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Habitat Element Curves: Development and Evaluation of Empirical versus Process-Based Models

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Habitat Element Curves: Development and Evaluation of Empirical versus Process-Based Models

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EXECUTIVE SUMMARY

Planning for conservation of biological diversity cannot simply be through "trial and error." Developing and applying methods to evaluate the potential effects and effectiveness of alternative biodiversity conservation management strategies helps reduce the uncertainty associated with conservation actions. Forest and habitat modeling is one approach that can offer insights into the long-term consequences of alternative strategies to conserve biodiversity.

Previous research on forest wildlife has demonstrated strong relationships with 3 classes of forest attributes: landscape horizontal pattern, stand-overstory species composition, and internal stand vertical structure. These 3 components have been demonstrated as necessary information elements to successfully predict the probability of stand occupancy by wildlife species. Hence if we can predict elements of these into the future, then we can at least have a liberal view of the consequences of alternative management strategies on species persistence. However, of these 3 classes of attributes, we are least confident in the internal stand-structure component. This is in part because of the large number of external or autogenic factors that influence internal stand structure.

Among the numerous approaches to modeling stand attributes, we evaluated 2 of the most commonly used approaches to developing habitat element curves: an empirical approach based on fitting statistical relationships between stand age and structural characteristics within the stand, and a mechanistic approach that projects changes in stand structure based on well understood dynamic processes. Empirical "statistical curve fitting" models are data intensive, and therefore tend to be expensive, whereas process-based models require a relatively detailed understanding of the dynamics of stand development. Hybrid models incorporate elements of both mechanistic modeling and empirical data analysis, and to some extent the two models we evaluated are actually hybrid models. We also briefly compared and contrasted these approaches to other methods, including mean value estimation, frequency distribution, spatial autocorrelation, matrix projection, and stochastic modeling approaches.

Chapter 1 documents the calibration of process-based habitat element curves using the FORECAST modeling system (developed under Hamish Kimmins, Clive Welham and Brad Sealy at the University of British Columbia) and a subset of Ontario Growth & Yield data for the Nipigon Forest Unit (NFU) in northwestern Ontario, and the Gorden Cosens Forest Unit (GCFU) in northeastern Ontario. Chapter 2 documents the development of empirically derived curves for northern and southern forested regions again using Ontario Growth & Yield data. In Chapter 3 we report on how we integrated model curves into the Patchworks forest harvest and scheduling model, and describe our approach for model testing. Chapter 4 compares model results with an independent set of data collected under controlled conditions of a long-term MNR research project directed by Dave Morris, and with results published in a few research papers.

In Chapter 4 the authors conclude that average canopy height can be reasonably well modeled by both process-based and empirical methods, but that model predictions will improve with better site productivity classifications. Both snag density and downed woody debris (DWD) volume are highly variable across all categories, and neither of the 2 modeling approaches predicted these variables very well and hence were not strongly defended by the results. Alternatively, a "stochastic model" based on a random normal deviate with a constant mean value across all forest types, but with variance changing with seral stage may provide a simpler but more defensible approach for modeling snag density. A mixed empirical and processes based modeling approach may be more defensible and realistic for DWD because early stages are highly random, but later stages follow the well-understood process of self- thinning. Percent canopy closure follows a relatively well defined successional path, so simple mean estimates for young, immature, mature, and late seral stages should work well for this attribute, but with variance also changing with seral stage. Shrub density is related to canopy opening and site productivity, so a simple matrix of expected mean density by 3 seral stages and ecosite-type may be appropriate here. Models

and modeling approaches should be selected based on a clear understanding of application objectives. Models of internal stand structure should be used cautiously, and modelers should error on the side of selecting the simplest, but most defensible models, even if this means loosing resolution in terms of projecting alternative management actions. For the purpose of evaluating management scenarios and future forest conditions, it may be best to use well behaving surrogate variables (e.g., tree height or canopy opening) in developing habitat models than using other preferred habitat variables that cannot be predicted well.

SOMMAIRE

La planification pour la conservation de la diversité biologique ne peut se faire à tâtonnement. L'élaboration et l'application des méthodes d'évaluation des répercussions potentielles et de l'efficacité d'autres stratégies de gestion de la conservation de la biodiversité aident à atténuer l'incertitude liée aux mesures de conservation. La modélisation des forêts et des habitats est une approche qui offre une perspective des conséquences à long terme des autres stratégies possibles en vue de conserver la biodiversité.

Les études menées sur la faune forestière démontrent qu'il existe des liens solides avec trois catégories de caractéristiques forestières : le modèle paysager horizontal, la composition des espèces des peuplements-étage dominant et la structure verticale des peuplements intérieurs. Il a été prouvé que ces trois composantes sont des éléments d'information nécessaires en vue de prévoir la probabilité de l'usage des peuplements par les espèces fauniques. Par conséquent, si nous pouvons prévoir des éléments de ces composantes à l'avenir, nous aurons alors un bon aperçu des conséquences des autres stratégies de gestion sur la pérennité des espèces. Cependant, le peuplement intérieur-la structure est une des trois composantes à laquelle nous nous fions le moins et ce, en partie parce que de nombreux facteurs externes ou autogéniques influent sur la structure des peuplements intérieurs.

Parmi les nombreuses façons de modéliser les caractéristiques des peuplements, nous avons évalué deux des approches utilisées le plus couramment en vue d'établir les courbes des éléments de l'habitat : une méthode empirique fondée sur l'agencement des relations statistiques entre l'âge des peuplements et les caractéristiques structurelles au sein de ceux-ci, et une méthode mécaniste qui prévoit les changements dans la structure des peuplements d'après des processus dynamiques bien compris. Les modèles empiriques « d'agencement des courbes statistiques » sont à grands volumes de données et ont donc tendance à être chers, alors que les modèles fondés sur les processus constituent une compréhension relativement détaillée des dynamiques du développement des peuplements. Les modèles hybrides comprennent des éléments de modélisation mécaniste et d'analyse de données empiriques et, dans une certaine mesure, les deux modèles que nous avons évalués sont en fait des modèles hybrides. Nous avons également comparé brièvement ces approches à d'autres méthodes, y compris l'estimation de la valeur moyenne, la distribution statistique, autocorrélation spatiale, la prévision matricielle et les méthodes de modélisation stochastique.

Le chapitre 1 porte sur la calibration des courbes des éléments de l'habitat fondées sur le processus, à l'aide du système de modélisation FORECAST (mis au point par Hamish Kimmins, Clive Welham et Brad Sealy, de l'University of British Columbia) et un sous-ensemble de données de l'Ontario Growth & Yield pour la Nipigon Forest Unit (NFU) au nord-ouest de l'Ontario, et le Gorden Cosens Forest Unit (GCFU) au nord-est de l'Ontario. Le chapitre 2 traite de l'établissement de courbes dérivées empiriquement pour les régions forestières, en utilisant là encore les données de l'Ontario Growth & Yield. Au chapitre 3, nous expliquons comment nous avons intégré les courbes de modèles dans le modèle de récolte et d'ordonnancement des forêts et nous décrivons notre méthode de test des modèles. Dans le chapitre 4, nous comparons les résultats des modèles à un ensemble distinct de données recueillies selon des

conditions contrôlées pour un projet de recherche à long terme du MRN dirigé par Dave Morris, dont les résultats ont été publiés dans différents rapports de recherche.

Au chapitre 4, les auteurs déterminent qu'on peut modéliser assez bien la hauteur moyenne d'un couvert à l'aide tant de méthodes fondées sur le processus que de méthodes empiriques, mais que les prévisions de modèles s'amélioreront avec de meilleures classifications de la productivité des emplacements. La densité des chicots et le volume des débris ligneux grossiers (DLG) varient beaucoup dans toutes les catégories et aucune de ces deux méthodes de modélisation n'a permis de calculer précisément ces variables, qui n'étaient donc pas solidement appuyées par les résultats. Autrement, un « modèle stochastique » fondé sur un écart aléatoire normal avec une valeur moyenne constante pour tous les types de forêts, mais comprenant un écart variant selon le stade évolutif pourrait fournir une approche plus simple mais plus défendable et réaliste pour les DLG, car les stades initiaux sont très aléatoires, mais les stades ultérieurs suivent le processus bien compris de l'auto-amincissement. Le pourcentage de fermeture du couvert suit un parcours évolutif assez bien défini. Par conséquent, les estimations simples de moyennes pour les stades de succession (jeune, immature, mature et dernier) devraient bien fonctionner pour cette caractéristique, mais l'écart variera aussi en ce qui concerne le stade de succession. La densité arbustive est liée à l'ouverture du couvert et à la productivité de l'emplacement, et une matrice simple de densité moyenne prévue par trois stades de succession et type d'écosite pourrait convenir ici. Les modèles et les approches de modélisation devraient être choisis en fonction d'une compréhension claire des objectifs d'application. Les modèles de structure interne du couvert devraient être utilisés avec prudence et si les modélisateurs doivent faire erreur, ce devrait être plutôt en choisissant les modèles les plus simples mais les plus défendables, même si cela signifie perdre de la résolution par rapport à la prévision d'autres mesures de gestion. En ce qui a trait à l'évaluation des scénarios de gestion et des conditions forestières futures, il serait peut-être préférable d'utiliser des variables subrogatives normales (comme la hauteur des arbres et l'ouverture du couvert) en vue d'élaborer des modèles d'habitats plutôt que d'utiliser d'autres variables d'habitat préférentielles pour lesquelles il est difficile de faire de bonnes prévisions.

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We wish to thank the Enhanced Forest Productivity Science Program and the Ontario Ministry of Natural Resources for funding this project. The EFPS program funded the majority of the FORECAST modeling work. We would also like to thank our partners for the development and previous calibration efforts on FORECAST, and the Provincial Growth and Yield program (under the Ontario Terrestrial Assessment Program) for providing stand development data for the project, the Landscape Guide science team for providing support for development of the empirical models and access to the Patchworks forest model for the Nipigon FMU. Also, we wish to thank the Stand Ecology Program (under Dr. Dave Morris, CNFER) for providing chronosequence data for model testing and Katrina Rempel and Brooke Pilley (CNFER) for desktop publishing this report.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

SOMMAIRE ii

ACKNOWLEDGMENTS iii

TABLE OF CONTENTS iv

LIST OF TABLES vi

LIST OF FIGURES viii

CHAPTER 1 — Development of Habitat Element Curves for the Nipigon and Gordon Cosens Forest Management Units using the Ecologically Based Forest Simulation Model FORECAST

INTRODUCTION 1
Project Objectives 1

METHODS 1
Model Description 1
Representation of Individual Stems 2
Decomposition & Nutrient Cycling 3
Model Calibration 3
Soils 5
Ecosystem Starting Condition 5
Analysis units 5
Development of stand attribute database 7

RESULTS & DISCUSSION 7
Stand attribute database 7
Comparison of model output against inventory data 7
Top height 7
Total shrub cover 8
Total snags 9

REFERENCES 10

CHAPTER 2 — Development of Empirical Habitat Element Curves for the Northern and Southern Boreal and Great-Lakes St Lawrence Regions Based on Ontario Growth and Yield data and Expert Interpretation

INTRODUCTION 13

METHODS 13
Description of PSP plots 13
Forest Stratification 14

RESULTS 15

DISCUSSION 15

LITERATURE CITED 15

CHAPTER 3 — Patchworks Integration & Initial Model Comparison

INTRODUCTION 25

METHODS 25

RESULTS 25
Class Groupings and Model Attributes 25
Comparison of habitat element (variable) predictions 25
Tree Height 25
Down Wood Debris 25

CHAPTER 4 — Comparative evaluation of model functional forms and external testing of model accuracy

INTRODUCTION 31

METHODS 31
Evaluation of the functional form and relative levels 31
External evaluation of model performance 32

RESULTS 32
Evaluation of the functional form and relative levels 32
Overall Large Snag Density 32
Black Spruce Mixed Conifer Snag Density 33
Trembling Aspen Snags 34
Hardwood Mixedwood Snags 34
Down Woody Debris 34
Black Spruce and Upland Conifer Height 36
External evaluation of model performance 36
Age versus seral stage 36
Tree Height 36
DWD Volume 40

DISCUSSION 40
Modeling Approaches 43
Mean or modal value estimation 43
Frequency Distribution 43
Statistical Curve Fitting 43
Spatial Autocorrelation Modeling 44
Process (Mechanistic) Modeling 44
Hybrid (Process/Empirical) Modeling 44
Matrix Age-Projection Modeling 44
Stochastic Modeling 44
Mixed Model Approach 45

Modeling Conclusions and Suggestionsfor Habitat Elements 45
Average Top Tree Height 45
Snag density 45
DWD volume 45
Percent canopy closure 46
Shrub density 46

REFERENCES 46

LIST OF TABLES

Table 1.1. Sources of calibration data for each of the tree species included in the FORECAST calibration data set 4

Table 1.2. The actual site index (based on breast-height age 50) for the different species included with the FORECAST calibration dataset. Jack pine is highlighted in red as it was used as the reference tree species for the representation of site quality in the model 4

Table 1.3. The development of ecostate files used to represent natural-stand starting conditions in FORECAST. The average length of assumed stand-replacing fire return intervals (FRI) is shown for each ecostate file 5

Table 1.4. A description of the natural stand analysis units simulated within FORECAST including assumptions regarding shrub competition, stand density and species composition. Transition pathways following harvest are also shown. 6

Table 1.5. A description of the managed stand analysis units simulated within FORECAST including assumptions regarding planting and natural regeneration (NR). All stands were assumed to be harvested using clearcut methods. Shrub species present in managed stands (not shown) were based on those present in the precursor natural stand. 6

Table 1.6. A description of the assumptions made with respect to the simulation of endemic natural disturbance regimes for different species within FORECAST 7

Table 1.7. A description of the assumptions made with respect to the simulation of endemic natural disturbance regimes for different species within FORECAST. 7

Table 2.1. Northwest standard forest units and class assignment 14

Table 2.2. Northeast standard forest units and class assignment. 14

Table 2.3. Zone assigned to permanent sample plotswithin each ecoregion. 15

Table 2.4. Percent (%) crown closure look-up table including south upland conifer (SUC), north upland conifer (NUC), south lowland conifer (SLC), north lowland conifer (NLC), south deciduous (SD), north deciduous (ND), south deciduous mixedwood (SDM), north deciduous mixedwood (NDM), south Great Lakes St. Lawrence pines (SGLSLP), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM) and south conifer mixedwood (SCM) 16

Table 2.5. Downed woody debris (m^3/hectare) look-up table including south upland conifer (SUC), north upland conifer (NUC), south lowland conifer (SLC), north lowland conifer (NLC), south deciduous (SD), north deciduous (ND), south deciduous mixedwood (SDM), north deciduous mixedwood (NDM), south Great Lakes St. Lawrence pines (SGLSLP), north Great Lakes St. Lawrence pines (NGLSLP), north conifer mixedwood (NCM) and south conifer mixedwood (SCM). 17

Table 2.6. Mean stand height (m/hectare) look-up table including south upland conifer (SUC), north upland conifer (NUC), south lowland conifer (SLC), north lowland conifer (NLC), south deciduous (SD), north deciduous (ND), south deciduous mixedwood (SDM), north deciduous mixedwood (NDM), south Great Lakes St. Lawrence pines (SGLSLP), north Great Lakes St. Lawrence pines (NGLSLP), north conifer mixedwood (NCM) and south conifer mixedwood (SCM). 18

Table 2.7. Number of snags (#/ha) in the south upland conifer class. Numbers of snags presented in 10 centimeter size classes 20

Table 2.8. Number of snags (#/ha) in the north upland conifer class. Numbers of snags presented in 10 centimeter size classes. 20

Table 2.9. Number of snags (#/ha) in the south lowland conifer class. Numbers of snags presented in 10 centimeter size classes. 21

Table 2.10. Number of snags (#/ha) in the north lowland conifer class. Numbers of snags presented in 10 centimeter size classes 21

Table 2.11. Number of snags (#/ha) in the south deciduous and south deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes 22

Table 2.12. Number of snags (#/ha) in the north deciduous and north deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes 22

Table 2.13. Number of snags (#/ha) in the south Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes. 23

Table 2.14. Number of snags (#/ha) in the north Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes. 23

Table 2.15. Number of snags (#/ha) in the south conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes. 24

Table 2.16. Number of snags (#/ha) in the north conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes. 24

Table 3.1. Class relationships between the process-based (FORECAST) and empirical-based habitat element curve (HEC) strata. 26

Table 3.2. Comparison of forest attributes for process-based (FORECAST) versus empirical based models. 27

LIST OF FIGURES

Figure 1.1. Diagrammatic representation of the fundamental ecosystem components and processes simulated within FORECAST including pathways of CO_2 loss to the atmosphere. 2

Figure 1.2. A schematic diagram illustrating the representation of the mass balance approach to nutrient cycling employed in the FORECAST model. The three main pools for nutrient storage are shown as well the specific processes regulating the movement of nutrients between pools and into/out of the ecosystem 3

Figure 1.3. A comparison of model output for top height for natural and managed stand types against vegetation inventory data from similar stand types 8

Figure 1.4. A comparison of model output for shrub cover (%) for natural and managed stand types against vegetation inventory data from similar stand types. 9

Figure 1.5. A comparison of model output for total snags (sph) for natural and managed stand types against vegetation inventory data from similar stand types. 10

Figure 2.1. Growth and yield plot layout. 13

Figure 2.2. Percent (%) crown closure for the north forest types including north upland conifer (NUC), north lowland conifer (NLC), north deciduous (ND), north deciduous mixedwood (NDM), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM). 19

Figure 2.3. Downed woody debris (m^3/hectare) for the north forest types including north upland conifer (NUC), north lowland conifer (NLC), north deciduous (ND), north deciduous mixedwood (NDM), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM) 19

Figure 2.4. Mean stand height (m/hectare) for the north forest types including north upland conifer (NUC), north lowland conifer (NLC), north deciduous (ND), north deciduous mixedwood (NDM), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM). 19

Figure 2.5. Number of snags (#/ha) in the south upland conifer class. Numbers of snags presented in 10 centimeter size classes. 20

Figure 2.6. Number of snags (#/ha) in the north upland conifer class. Numbers of snags presented in 10 centimeter size classes. 20

Figure 2.7. Number of snags (#/ha) in the south lowland conifer class. Numbers of snags presented in 10 centimeter size classes 21

Figure 2.8. Number of snags (#/ha) in the north lowland conifer class. Numbers of snags presented in 10 centimeter size classes. 21

Figure 2.9. Number of snags (#/ha) in the south deciduous and south deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes. * Data were not available in the south deciduous mixed class and we have assumed that the deciduous is approximately the same. 22

Figure 2.10. Number of snags (#/ha) in the north deciduous and north deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes. *Data were not available in the north deciduous mixed class and we have assumed that the deciduous is approximately the same. 22

Figure 2.11. Number of snags (#/ha) in the south Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes. 23

Figure 2.12. Number of snags (#/ha) in the north Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes. 23

Figure 2.13. Number of snags (#/ha) in the south conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes. 24

Figure 2.14. Number of snags (#/ha) in the north conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes. 24

Figure 3.1. Comparative plot of black spruce growth curves. 27

Figure 3.2. Comparative plot of trembling aspen growth curves. 27

Figure 3.3. FORECAST curve for Total DWD, Black Spruce (AU 101, Table 1.4). 28

Figure 3.4. EMPIRICAL curve for total DWD, upland conifer analysis unit. Lower curve is the EMPIRICAL model. Upper curve is estimated model based on removal of zero-estimate date points. 28

Figure 3.5. Comparative maps of down woody debris predictions (through Patchworks) based on EMPIRICAL versus FORECAST models. Each colour gradation represents a change of 1 standard deviation above or below the mean. 28

Figure 3.6. Northern upland conifer and upland black spruce models for all conifer snags >20 cm (FORECAST) and all snags in the 21-30 cm range (EMPIRICAL). F 200 series is FORECAST curve for managed stands, and 100 series is for natural origin stands. Scale is logarithmic, so 100 series density is almost 2 orders of magnitude higher at year 0. 29

Figure 3.7. Comparative maps of snag density predictions (through Patchworks) based on EMPIRICAL (sn21-gt50) versus FORECAST (fallsnags) models. Each colour gradation represents a change of 1 standard deviation above or below the mean. 29

Figure 4.1. **(A and B).** Large snag (>20cm dbh) density for black spruce dominated mixed conifer stands (Sb Mix). The y-scale is reduced in Figure 4.1B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented. The ecosite 20 data is only represented in Figure 4.1A. 33

Figure 4.2. **(A and B).** Large snag (>20cm dbh) density for conifer dominated mixedwood stands. The y-scale is reduced in Figure 4.2B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented. 34

Figure 4.3. **(A and B).** Large snag (>20cm dbh) density for aspen (Po) dominated deciduous stands. The y-scale is reduced in Figure 4.3B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented. 35

Figure 4.4. **(A and B).** Large snag (>20cm dbh) density for deciduous leading mixedwood (Hdwd Mix) stands. The y-scale is reduced in Figure 4.4B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented 35

Figure 4.5. Down woody debris for black spruce dominated mixed conifer stands. 36

Figure 4.6. FORECAST, empirical and ecosite 20 height data overlaid on Plonski's Yield Tables for black spruce dominated mixed conifer stands 36

Figure 4.7. Comparison of seral stages (pre-sapling, sapling, immature, mature and late) assigned by field crews versus FRI stand age. Observers could only clearly discriminate 3 seral stages, as pre-sapling and sapling, and mature and late seral stages were confused. 37

Figure 4.8. Tree heights versus age. (a) plot of FRI age versus height; (b) result of removing outlier data points; (c) & (d) regression of predicted overstory height versus FRI estimates of overstory height (outlier data points removed in (d)); both reference lines (slope = 1) and estimated slopes are given in (c) and (d). 37

Figure 4.9. Snag density model evaluation. (a) stand age versus observed snag density; (b) dispersion of observed snag density among age-classes; (c) regression of predicted versus observed values for FORECAST model, and (e) empirical model; (d) dispersion of predicted snag density among age-classes for FORECAST model and (f) empirical model; both reference lines (slope = 1) and estimated slopes are given in (c) and (e). Observed values truncated at 2000 in (c) and (e) 38

Figure 4.10. DWD model evaluation; regression of predicted versus observed DWD volume for (a) FORECAST and (c) empirical model; dispersion of predicted values for (b) FORECAST and (d) empirical models; both reference lines (slope = 1) and estimated slopes are given in (a) and (c). Observed values truncated at 100 for the plots for (a) & (c). 39

Figure 4.11. Regression of predicted downed log density (FORECAST model) versus observed downed log density. Observed values truncated at 2000. Both reference lines (slope = 1) and estimated slopes are given 40

Figure 4.12. Observed dispersion of snags and DWD by field-estimated seral stage. 40

Figure 4.13. Schematic view of a stochastic model of large-snag density, where modal values and the degree and form of variance changes with seral stage. The shape of the frequency distribution for Seral Stage 1 is based on Perera et al. 2008, and data presented in Figure 4.12 42

Figure 4.14. With a relatively well defined variable such as tree height, process-based models could integrate with the models by predicting how the modal condition of tree heights will change, in a relative manner, given certain changes in climatic conditions or soil productivity. Given that snag density has been shown to be related to density of large trees within the stand (Furguson and Archibald, 2002), this relationship could also feed into snag density estimates.....43

Figure 4.15. Mixed model of pre-fire and post-fire inputs to DWD, where pre-fire inputs are modeled stochastically, and post-fire inputs are modeled using a hybrid processes-based model. 44

Chapter 1

Development of Habitat Element Curves for the Nipigon and Gordon Cosens Forest Management Units using the Ecologically Based Forest Simulation Model FORECAST

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INTRODUCTION

Forest and habitat modeling can be used to evaluate the potential impacts of alternative biodiversity conservation strategies. The effective planning for preservation of biodiversity in managed forest landscapes requires the application of decision support systems (DSS) to evaluate the potential impact of alternative stand and landscape management activities on indicators of habitat suitability. DSSs are most effective when implemented within an adaptive management cycle (after Walters, 1986; Rauscher, 1999) including a well defined set of indicators, monitoring systems, and mechanisms for feedback from researchers, industry, and stakeholder groups. As outlined by Seely *et al.* (2004) the DSS plays a critical role in this process by:

- highlighting potential conflicts between competing management objectives,
- providing a common, science-based framework for stakeholders to evaluate the potential consequences of specific management options,
- conveying knowledge about the long-term dynamics of forest ecosystems, and
- providing guidance for the monitoring process by projecting expected trends in selected indicators.

To model consequences for forest management activities for forest wildlife, we need to predict at least 3 components of the future: landscape horizontal pattern, stand-overstory species composition, and internal stand vertical structure. These 3 components have been demonstrated as necessary information elements to successfully predict the probability of stand occupancy by wildlife species. Hence if we can predict these 3 elements into the future, then we can at least have a "liberal" view of the consequences of alternative management strategies on species persistence. Of these 3 elements, we are least confident in the internal stand-structure component. This is in part because Forest Inventory stand-age relates poorly to internal stand-structure; hence statistical models of the relationship are either poor, or misleading. A stronger approach is to develop relationships based on well understood stand development and mortality processes.

Project Objectives

The principal objective of this project was to use the process-based stand development model (FORECAST), to develop a database of stand-level curves for critical stand-level habitat elements (stand height, snags, coarse woody material, and shrub cover). This database will be accessed by harvest scheduling and succession models (e.g. Patchworks) and used to facilitate prediction of future forest habitat conditions (see Seely *et al.*2004).

Specific Project Objectives include the following:

1. Calibrate the FORECAST model for the boreal forest types within the Lake Nipigon and Gordon Cosens forest management units within northwestern Ontario.
2. Create a series of analysis units stratified by overstory classes and productivity classes to represent the range of forest types that occur within the forest management areas
3. Generate a stand attribute database including output for each analysis unit including volume, top height, species composition, snags, CWD, and shrub cover.

METHODS

Model Description

FORECAST is a management-oriented, stand-level forest growth and ecosystem dynamics simulator. The model was designed to accommodate a wide variety of harvesting and silvicultural systems in order to compare and contrast their effect upon forest productivity, stand dynamics and a series of biophysical indicators of non-timber values. FORECAST can be used to make projections on the development of stand structural attributes associated with wildlife habitat suitability including large diameter snags, coarse woody debris and shrub cover. The projection of stand growth and ecosystem dynamics is based on a representation of the rates of key ecological processes regulating the availability of, and competition for, light and nutrient resources (Fig.1.1). The rates of these processes are calculated from historical bioassay

data (e.g. biomass accumulation in component pools, mortality, litterfall, etc.) by relating 'biologically active' biomass components (e.g. foliage and small roots) with calculations of nutrient uptake, the capture of light energy, and net primary production. In essence the model is calibrated internally such that the combination of linked processes and their derived rates reproduces the patterns of species and site-specific growth observed in the historical bioassay data. The model uses this method to generate information (simulation rules) for each tree and plant species to be represented. These simulation rules are subsequently used to model growth as function of resource availability and competition in the case of multi-species stands. The following list is an example of some of the simulation rules governing future tree growth derived from the set-up internal calibration process.

- **Photosynthetic efficiency per unit foliage biomass**: based on relationships between foliage biomass, simulated self-shading levels, and net primary productivity accounting for litterfall rates and mortality.
- **Nutrient uptake requirements**: based on rates of biomass accumulation and literature-based estimates of nutrient concentrations in different biomass components on different site qualities
- **Light-related measures of tree and foliage mortality**: Using stand density input data in combination with simulated light profiles, light levels at which foliage and tree mortality occur are estimated for each species.

As a management model, FORECAST can simulate a wide variety of activities including fertilization, brushing, partial harvesting, mixedwood management, etc. Disturbances such as fire and insect defoliation may also be represented. Volume projections generated by FORECAST are ultimately constrained by the potential yields of single species stands as specified in the calibration data for a range of site qualities. Growth and yield in complex stands is based on a simulated partitioning of limited resources (light and nutrients) among species and age cohorts. The biological properties of individual species determine their relative competitiveness for limited resources. A more complete description

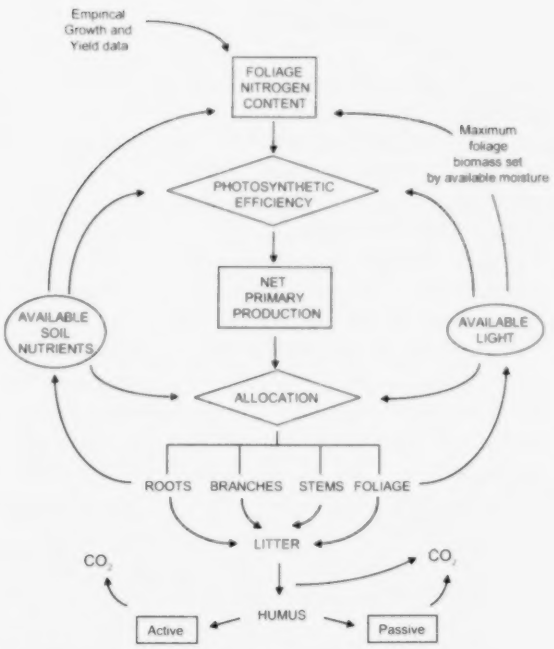

Figure 1.1. Diagrammatic representation of the fundamental ecosystem components and processes simulated within FORECAST including pathways of CO_2 loss to the atmosphere.

of model functionality and further details of FORECAST calibration are provided in Kimmins *et al.* (1999), Seely *et al.* (1999), and Seely (2004).

Representation of Individual Stems

Though FORECAST performs many of its calculations at the stand level, it includes a submodel that disaggregates stand-level growth into the growth of individual stems. This is done using a method which takes information about stem size distributions at different stand ages to simulate differential growth rates in individual stems (see Kimmins *et al.* 1999). Using this approach, the distribution in projected stems sizes widens as stands age. DBH and top height and are calculated for each stem and subsequently used to calculate a merchantable volume using a taper function approach (Kozak 1988). In addition to DBH and top height data, FORECAST also estimates the height along the stem where the canopy begins (e.g. where live braches start) based on a simulation of the light profile through the canopy and species-specific parameters related to shade tolerance.

Decomposition & Nutrient Cycling

Decomposition and nutrient cycling are simulated in FORECAST using a method in which specific biomass components are transferred at the time of litterfall or mortality, to one of a series of litter types. Each litter type has unique properties in terms of decomposition rates, nutrient concentrations and humus formation.

The model employs a mass balance approach to keep track of the total pool of nutrients within the ecosystem and any import or export of nutrients to and from the ecosystem (Fig. 1.2). Nutrient storage and release from decomposing litter and soil organic matter represents the largest source of nutrients into the plant available pool. Tree growth is ultimately limited by available nutrients such that if the availability of nutrients is less than that required to support the expected annual biomass increment of the trees, the actual growth rate will be restricted to an increment level supported by its simulated nutrient uptake.

Model Calibration

The calibration data developed for the project was designed to represent boreal forest ecosystems within northwestern Ontario. The datasets can be broken into tree data, plant data and soil data components.

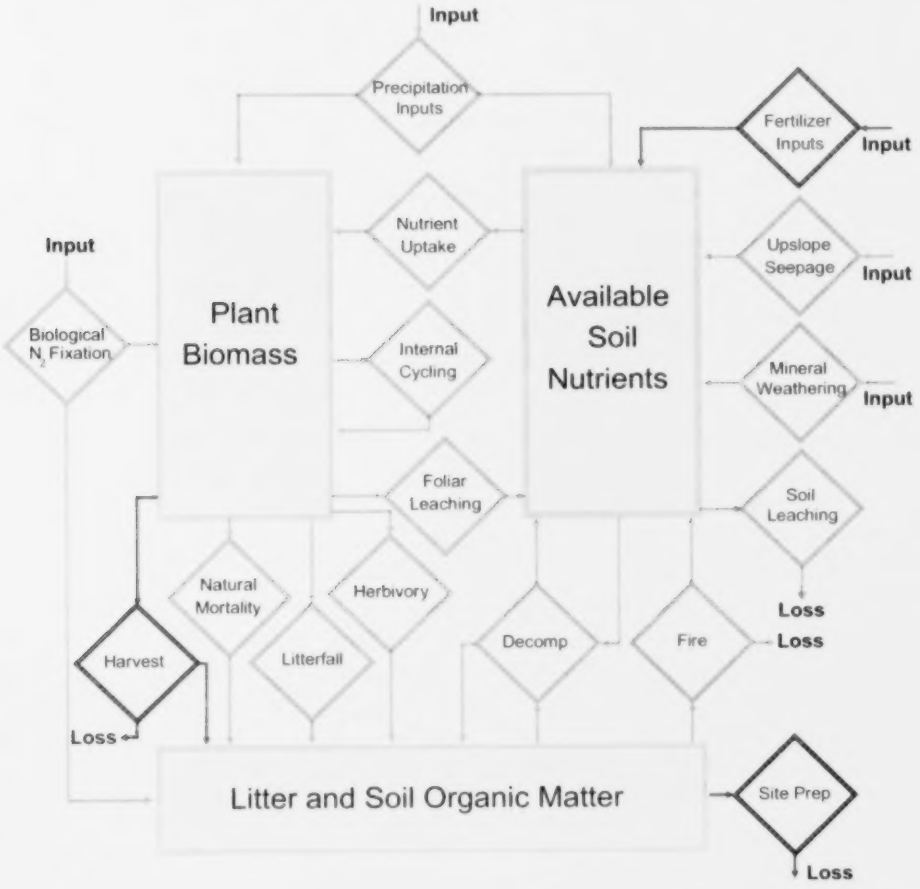

Figure 1.2. A schematic diagram illustrating the representation of the mass balance approach to nutrient cycling employed in the FORECAST model. The three main pools for nutrient storage are shown as well the specific processes regulating the movement of nutrients between pools and into/out of the ecosystem. Green diamonds indicate biological processes while red and blue diamonds indicate the geochemical cycle and management impacts on nutrient cycling, respectively.

Tree data

Tree species within the data set included Gordon Cosens forest management units jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*) and balsam fir (*Abies balsamea*). The core biomass accumulation and height growth data for each species were generated using yield table data in combination with species-specific allometric biomass equations (Table 1.1.). Below-ground biomass was estimated for each tree species based on the equations provided in Kurz *et al.* (1996). Other data describing nutrient concentrations in various biomass components, light utilization and extinction curves, and litterfall rates were derived from a combination of literature sources (see Table 1.1) and existing FORECAST calibration data sets. The site index values used to estimate species-specific relative biomass accumulation rates on poor, medium and good sites (through linkage with yield tables) are shown in Table 1.2.

Table 1.1. Sources of calibration data for each of the tree species included in the FORECAST calibration data set.

Tree species	Yield data	Biomass equations	Other
Jack Pine *(Pinus banksiana)*	Plonski 1974[1]	Perala & Alban 1994, Ker 1984	Messier et al 1998, Kimmins et al.1979, Kurz et al. 1996, Vogel & Gower 1998,Thiffault et al. 2006,Ferguson & Elkie 2003
Black Spruce *(Picea mariana)*	Plonski 1974[1]	Perala & Alban 1994, Freedman et al. 1982	Messier et al 1998, Kimmins et al. 1979, Kurz et al. 1996, ,Ferguson & Elkie 2003, Stadt et al. 2005, Thiffault et al. 2006
Trembling Aspen *(Populus tremuloides)*	Plonski 1974[1]	Perala & Alban 1994, Young et al. 1980	Messier et al 1998, Kimmins et al. 1979, Kurz et al. 1996, Harvey & van den Driessche 1999, Vanderwel et al. 2006, Alban et al. 1991, Lindroth et al. 2001, Perala and Alban 1993
White Birch *(Betula papyrifera)*	Plonksi 1974[1]	Perala & Alban 1994, Ker 1984	Messier et al 1998, Kimmins et al 1979, Kurz et al. 1996, Vanderwel et al. 2006, Alban et al. 1992, Lindroth et al. 2001
Balsam Fir *(Abies balsamea)*	Plonski 1974[1], Baskerville 1966, Griffin & Johnson 1980	Perala & Alban 1994, Kerr 1984	Messier et al 1998, Kimmins et al 1979, Kurz et al. 1996, Johnston 1986, Stadt et al. 2005

[1] Updated according to URL: http://flash.lakeheadu.ca/~fluckai/nytweb.html.

Table 1.2. The actual site index (based on breast-height age 50) for the different species included with the FORECAST calibration dataset. Jack pine is highlighted in red as it was used as the reference tree species for the representation of site quality in the model.

	Species[1]					
Site Class	Pj	Sb	At	Bw	Bf	Yield Class[2]
Dry Poor	12	10	16	13	12	**1**
Mesic Medium	16	13	20	16	15	**2**
Mesic Rich	19	16	23	19	18	**3**

[1] Species codes: Pj = jack pine, Sb = black spruce, At = trembling aspen, Bw = white birch, Bf = balsam fir.

[2] Yield classes used for conversion to height curves and development of biomass data based on Plonksi (1974).

Understory vegetation

The representation of understory vegetation within FORECAST was limited to common shrub species in Ontario's boreal forests. These included beaked hazel (*Corylus cornuta*) and low sweet blueberry (*Vaccinium angustifolium*). While we recognize there are many different species that comprise the entire shrub community, these two common species were selected and modeled to represent the total shrub community. Data required to represent shrub growth in FORECAST include: biomass accumulation rates, height growth, nutrient concentrations, and light response curves. These data were derived from a range of sources including literature sources (Brumelis and Carleton 1989, Johnson 1992, Légaré *et al.* 2001, Okland and Eilertsen 1996, Kimmins *et al.* 1979, Messier *et al.* 1998, Aubin *et al.* 2000, Hunt *et al.* 2003, Palviainen *et al.* 2005) and general knowledge of the autecology of each selected shrub species.

Soils

Decomposition rates of the specific litter types are defined based on the results of extensive field incubation experiments conducted across British Columbia and Canada (e.g. Camiré *et al.*, 2002). Mean residence times for *active* and *passive* humus types are estimated from climate data utilizing a Q10 multiplier. Residence times for ecosystem types within Ontario boreal forests typically range from 25 to 50 years for active humus and 400 to 750 years for passive humus.

Model Application

Ecosystem Starting Condition

Prior to using the model to simulate the growth of the different mixedwood stands and associated treatments, it was necessary to run the model in set-up mode to establish initial site conditions. In this stage, the model is run with nutrient feedback turned off to allow it to accumulate vegetation, litter and soil organic matter representative of the site(s) to be modeled, and which reflects the historical patterns of accumulation. This is typically achieved by simulating the known or estimated natural disturbance and/or management history of the site (see Seely *et al.* 1999 for a detailed description). Using this approach a series of starting condition (ecostate) files were created (see Table 1.3) to represent the starting conditions for each of the analysis units described in Tables 1.4 and 1.5.

Analysis units

A series of natural stand analysis units (for simulation in FORECAST) were developed to represent the general range of stand types that occur within the boreal forests of northwestern Ontario. These were created by stratifying by overstory cover type and productivity class (Table 1.4). An effort was made to link these analysis units with previous analysis units constructed for an analysis of the Lake Nipigon Forest Region (Spatial Planning Systems 2005). In addition, managed stand analysis units were created for each of the natural stand units based on a clearcut harvest (Table 1.5).

Table 1.3. The development of ecostate files used to represent natural-stand starting conditions in FORECAST. The average length of assumed stand-replacing fire return intervals (FRI) is shown for each ecostate file.

Ecostate ID[1]	FRI	Density	Sp1	Sp1%	Sp2	Sp2%	Fire cycles	Build-up Time
Sb14	125	2500	Sb	90	Pj	10	4	625
Sb16	125	3000	Sb	65	Pj	35	8	1125
Sb12	200	1500	Sb	100		0	2	600
Mix17	125	3000	Sb	70	At	30	12	1625
Mix15	125	2500	Sb	70	At	30	8	1125
At18	125	5000	At	80	Sb	20	8	1125
Pj12	100	1200	Pj	65	Sb	35	5	600
Pj15	100	3000	Pj	60	Sb	40	10	1100

[1] The number indicates the reference site index used in the simulation.

Table 1.4. A description of the natural stand analysis units simulated within FORECAST including assumptions regarding shrub competition, stand density and species composition. Transition pathways following harvest are also shown.

ID	Description	Nipigon units[1]	Moisture Class	Productivity Class	Ecostate File	NW Ecosites[2]	Shrub comp. level	Shrub Sp.[3]	Stem density (sph)	Sp1	Sp2	Sp3	Sp1%	Sp2%	Sp3%	Managed stand transition
101	Sb dominated mixed conifer	23	dry	medium-poor	Sb14	14,20	medium	C	2500	Sb	Pj	At	60	30	10	201
102	Sb dominated mixed conifer	25,26	mesic	medium	Sb16	31,25	low	V	3000	Sb	Pj	At	60	25	15	202
103	SB dominated lowlands	24	wet	poor	Sb12	35,36	medium	V	1500	Sb			100			203
104	Conifer leading mixedwood	6,7,22	mesic	medium-good	Mix17	26,27	medium	C	3000	Sb	Bf	At	40	30	30	204
105	Conifer leading upland mixedwood	5,21	dry	medium	Mix15	21	low	C	2500	Sb	Bf	At	45	30	25	205
106	Aspen dominated	10,11,18	mesic	medium-good	At18	23,28,29	medium	C	5000	At	Bf	Sb	80	10	10	206
107	Birch dominated	4,3,13	mesic	medium-good	At18	28,30	medium-high	C	5000	Bw	Bf	Pj	80	10	10	207
108	Poor upland conifer	12,17	dry	poor	Pj12	11,12, 13,15	low	V	1200	Pj	Sb		75	25		208
109	Deciduous leading mixedwood	9,8	mesic	medium	Mix15	23	medium	C	3000	At	Bw	Bf	50	25	25	209
110	Bf dominated mixed conifer	2,1	mesic	medium-good	Mix17	27	medium-high	C	2500	Bf	Sb	At	65	20	15	210
111	Pj Dominated mixed conifer	14,15, 16,20	dry-mesic	medium	Pj15	14,20	medium	C	4000	Pj	Sb	At	60	20	10	211

Table 1.5. A description of the managed stand analysis units simulated within FORECAST including assumptions regarding planting and natural regeneration (NR). All stands were assumed to be harvested using clearcut methods. Shrub species present in managed stands (not shown) were based on those present in the precursor natural stand.

ID	Post-harvest description	Nipigon units[1]	From AU	Moisture Class	Productivity Class	NW Ecosites[2]	Species prior to harvest	Planted Sp1	Planted Sp2	NR Sp1	NR Sp2	Year NR Sp1	Year NR Sp2
201	Sb dominated mixed conifer	23	101	dry	medium-poor	14,20	Sb, Pj, At	Sb,800	Pj, 400	At, 250		2	
202	Sb dominated mixedwood	25,26	102	mesic	medium	31,25	Sb, Pj, At	Sb,1000	Pj, 500	At, 750		2	
203	Sb dominated lowlands	24	103	wet	poor	35,36	Sb	Sb,1200					
204	Conifer leading mixedwood	6	104	mesic	medium-good	26,27	Sb, Bf, At	Sb,1000	Pj, 500	At, 1250	Bf, 500	2	5
205	Conifer leading upland mixedwood	5	105	dry	medium	21	Sb, Bf, At	Sb,750	Pj, 750	At, 750	Bf, 500	2	5
206	Conifer leading mixedwood (At)	10	106	mesic	medium-good	23,28,29	At, Bf, Sb	Sb,1000	Pj, 500	At, 1500	Bf, 500	2	5
207	Conifer leading mixedwood (Bw)	4	107	mesic	medium-good	28,30	Bw, Bf, Pj	Sb,750	Pj, 750	Bw, 1500	Bf, 500	2	5
208	Poor upland conifer	12,17	108	dry	poor	11,12,13,15	Pj, Sb	Pj,1000	Sb, 500				
209	Conifer leading mixedwood (At)	9	109	mesic	medium	23	At, Bw, Bf	Sb,1000	Pj, 500	At, 1500		2	
210	Mixed conifer with Bf	2	110	mesic	medium	27	Bf, Sb, At	Sb, 1000		At, 250	Bf, 500	2	5
211	Mixed conifer with Pj	14	111	dry	medium	14,20	Pj, Sb, At	Pj,1000	Sb, 500	At, 250		2	

[1] Associated analysis units as described in a previous analysis of the Lake Nipigon Forest (Spatial Planning Systems 2005).

[2] Associated ecosites based on the Field Guide for NW Ontario Forest Ecosystems (Racey *et al.* 1996).

[3] C = *Corylus cornuta*, and V= *Vaccinium angustifolium*.

Development of stand attribute database

Each of the analysis units described in Tables 1.4 and 1.5 were simulated in FORECAST to generate time series curves of stand attributes including: volume by species, top height by species, stand density by species, snags, logs, CWD volume, and shrub cover. To represent the effect of endemic disturbance agents on snag and log recruitment an endemic disturbance regime was imposed on each species for all runs (Table 1.6).

Comparison of model output against inventory data

To evaluate model performance, projections for representative natural and managed stand analysis units were plotted against vegetation inventory permanent sample plot (PSP) data for similar stand types based on forest unit and northwestern Ontario ecosites. PSP data were provided through Ontario's Forest Growth and Yield Program - Ontario Terrestrial Assessment Program (OnTAP). For field collection and data summary methods refer to Hayden *et al.* 1995.

Comparisons were made for top height, total shrub cover and total snags. Specific analysis units were compared against the most similar PSPs in the database (Table 1.7).

Table 1.6. A description of the assumptions made with respect to the simulation of endemic natural disturbance regimes for different species within FORECAST.

	Endemic Disturbance Regime		
Tree Species	Initial event (yr.)	Frequency (yrs.)	Mortality (%)
jack pine (Pj)	40	15	3%
black spruce (Sb)	45	15	3%
trembling aspen (At)	35	10	3%
white birch (Bw)	35	10	3%
balsam fir (Bf)	70	15	3%

RESULTS & DISCUSSION

Stand attribute database

A stand attribute database was created by summarizing model output for each analysis unit on 5-year time steps.

Comparison of model output against inventory data

As described above, model output for top height, total shrub cover and total snags were compared against selected Ontario PSP measurement data. Caution should be used in evaluating these direct comparisons because while PSPs are organized by forest unit and leading species etc., they represent stands with different disturbance histories in different locations. This method of model evaluation is not equivalent to a repeated measures approach in which the same plots are sampled at different points in time. Thus, much of the variance in field data is derived from differences other than simply stand age.

Top height

A comparison of simulated top height against values recorded for comparable PSPs (see Table 1.7) is shown for four forest types in Figure 1.3. Simulated

Table 1.7. A description of the assumptions made with respect to the simulation of endemic natural disturbance regimes for different species within FORECAST.

	Analysis Units		PSP attributes	
Stand description	Natural	Managed	NW Forest Unit	NW ecosites
Aspen dominated hardwood	106	206	HrDom	16, 19
Jack pine dominated mixed conifer	111	211	PjDee	20
Conifer leading mixedwood	105	205	ConMix	21
Black spruce dominated mixed conifer	101	201	SbDee	20

height growth was similar to that measured in the PSPs for all stands with the exception of the aspen dominated hardwood in which case the modelled top height exceeded that observed in older plots. One reason for this discrepancy could be the fact the PSP plots represent the drier end of the range of ecosites represented by the associated FORECAST analysis units (106 & 206) (see Tables 1.4 and 1.5). In general, top height in managed stands was slightly higher than that in natural stands. This is related to the fact the managed stands start with planted trees and typically face slightly less competition from minor vegetation relative to unmanaged counterparts.

Total shrub cover

A comparison of simulated total shrub cover against values recorded in comparable PSPs (see Table 1.7) is shown for four forest types in Figure 1.4. In general there was a large degree of variation in total shrub cover in the PSP data. As such, temporal trends were difficult to identify. In most cases however, there was a weak general trend for elevated shrub cover during stand initiation followed by a decline and an increase later in stand development. Factors that influence shrub cover include availability of shrub propagules at the time of stand initiation, density of tree species, and soil properties.

The model showed similar but more pronounced patterns depending on the forest type. The aspen dominated hardwood stand type had the highest shrub cover in both the PSP data and model output, while the black spruce dominated mixed conifer stand types generally had the lowest values. This is consistent with patterns of below canopy light. Interestingly, the managed black spruce dominated mixed conifer stand had one

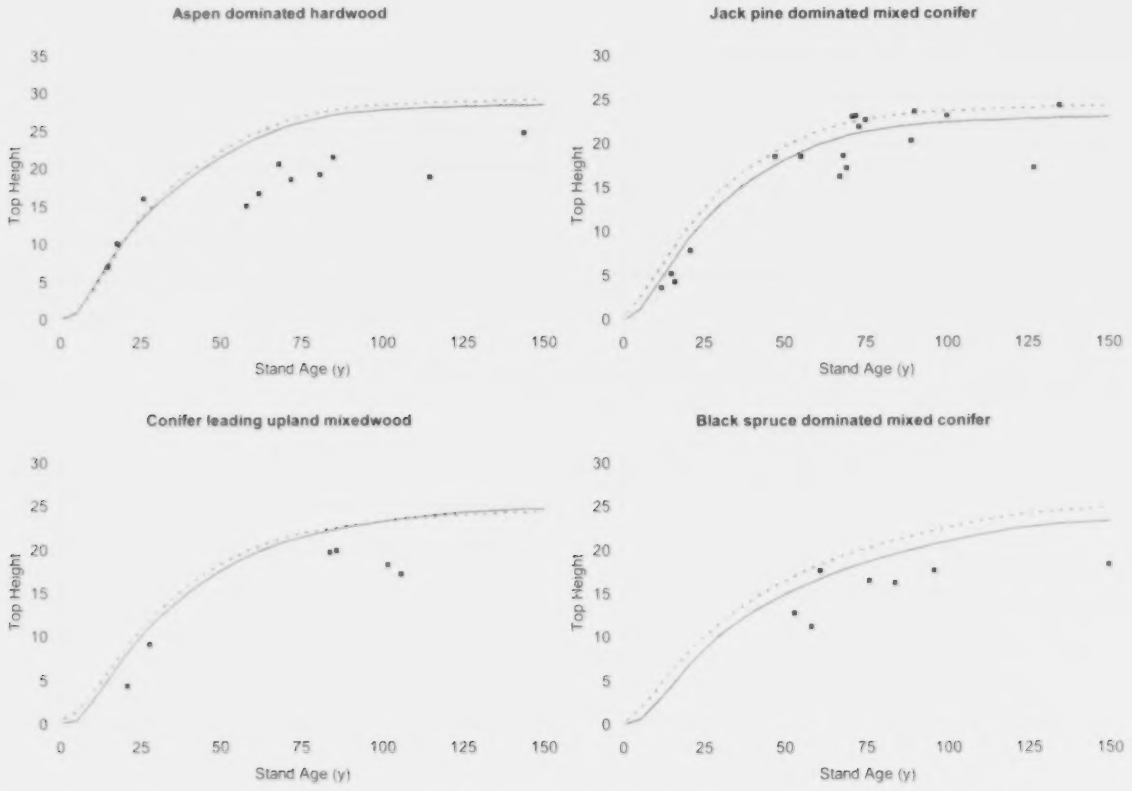

Figure 1.3. A comparison of model output for top height for natural and managed stand types against vegetation inventory data from similar stand types. Dashed lines represent simulated managed stands and solid lines represent simulated natural stands. Points represent inventory data from stands of different ages. The analysis units and PSPs shown for the specific stand types are outlined in Table 1.7

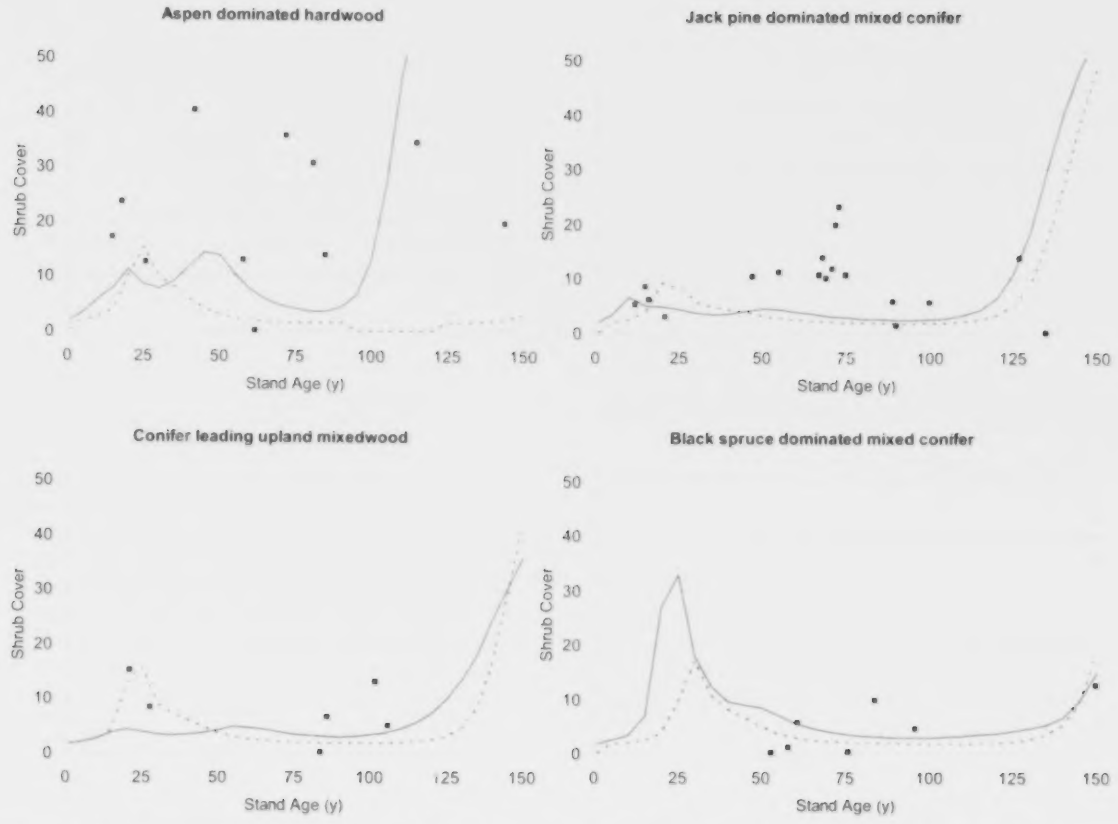

Figure 1.4. A comparison of model output for shrub cover (%) for natural and managed stand types against vegetation inventory data from similar stand types. Dashed lines represent simulated managed stands and solid lines represent simulated natural stands. Points represent inventory data from stands of different ages. The analysis units and PSPs shown for the specific stand types are outlined in Table 1.7.

of the highest simulated early shrub cover levels. This is a function of the relatively slower growth rates in young black spruce relative to pine and aspen which allows the shrubs to become more established early on. However, as the black spruce canopy develops, below-canopy light levels drop substantially and shrub cover declines accordingly.

Total snags

A comparison of total simulated snags per hectare against values recorded in comparable PSPs (see Table 1.7) is shown for four forest types in Figure 1.5. Similar to shrub cover, there was considerable variation in total numbers of snags in the PSP data. Thus variation is related to differences in stand density and differences in the activities of endemic disturbance agents during stand development. Projected levels of total snags were in the range of those measured in PSP plots. While FORECAST can distinguish snags by species and diameter classes, simulated snags shown in Figure 1.5 included all standing dead trees at a given stand age. One noticeable difference between simulated and measured snags was the large numbers of snags in simulated young natural stands. These snags are the legacy of the previous stand that was assumed to be killed by stand-replacing fire. The absence of snags in young PSP stands would suggest that the young PSP stands were not derived from natural disturbance events but rather from planting following a harvest. Alternatively, the stands were sampled after snags from the previous stand had fallen.

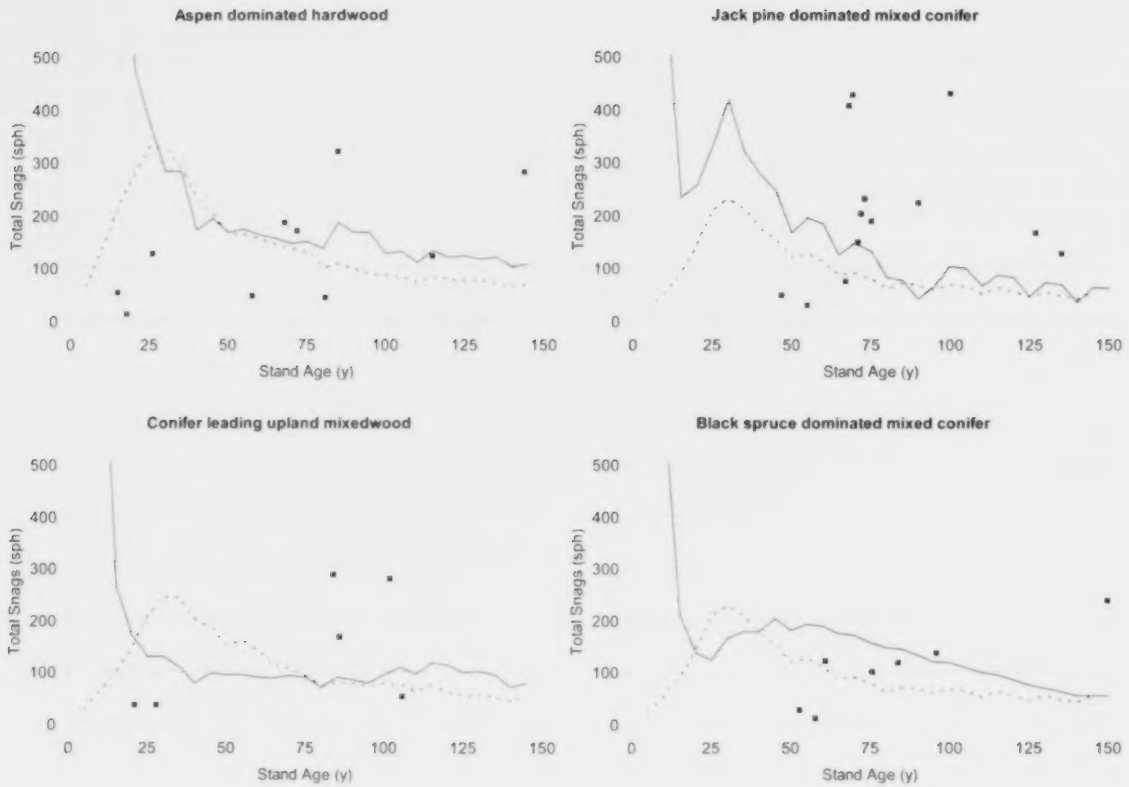

Figure 1.5. A comparison of model output for total snags (sph) for natural and managed stand types against vegetation inventory data from similar stand types. Dashed lines represent simulated managed stands and solid lines represent simulated natural stands. Points represent inventory data from stands of different ages. The analysis units and PSPs shown for the specific stand types are outlined in Table 1.7.

The general pattern of snags in simulated stands (excluding snags from the previous stand in the case of natural stands) was a peak in snags during the stand-self thinning stage followed by a gradual decline in snags as the stands age. If only large diameter snags were considered there would be a general increase in the number of snags as stands aged. The other factor to consider is that larger snags tend to last longer than smaller diameter snags.

When considering snags as an indicator of habitat suitability or quality, it is important to specify the characteristics of snags that provide habitat. In general, it is thought that snags that are greater 20-25cm diameter are more important with respect to habitat (e.g. Seely *et al.* 2004).

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Chapter 2

Development of Empirical Habitat Element Curves for the Northern and Southern Boreal and Great-Lakes St Lawrence Regions Based on Ontario Growth and Yield data and Expert Interpretation

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INTRODUCTION

The spatial habitat models used in support of the Landscape Guide scenario analyses required development of habitat element curves to project stand-level conditions for future forests. A project to rapidly develop a first-iteration of these curves was undertaken to use existing permanent sample plot (PSP) data from Ontario's Forest Growth and Yield Program, which is run under the general Ontario Terrestrial Assessment Program (OnTAP). This report documents the procedures and stratification used in developing the habitat element curves, and includes a description of how expert opinion was used to refine the final curves.

METHODS

Description of PSP plots

Plots consist of a large mortality plot (radius of 45.14 m; 6400 m^2) to measure tree mortality & downed and woody debris (Figure 2.1). Within each mortality plot there are 3 growth plots (radius of 11.28 m; 400 m^2). Within each growth plot there are 3 shrub plots (radius 2.82 m; 25 m^2) to measure medium to high shrub composition and % cover. Also, data is collected on tree seedlings, tree regeneration, tree saplings, low shrubs and ground vegetation. When tree regeneration and sapling counts are high then 3 regeneration plots (1.13 m) within each shrub plot are used.

For further information on the field collection and data summary methods refer to Hayden et al. 1995.

The PSP measurements include the following attributes:

a. number of snags (hardwood-softwood, 10 cm size classes)
b. volume down woody debris (m^3) (hardwood-softwood, 10 cm size classes)
c. percent cover ground vegetation (herbs, ferns, grasses and sedges, feather mosses, sphagnum moss, other mosses, cladina and other bryophytes)
d. stand age,
e. percent crown closure,
f. ecosite type,
g. forest unit,
h. tree species composition,
i. tree density,
j. percent shrub cover for ericeous (0-49.9 cm and 50-199.9 cm) and non-ericaceous (0-49.9 cm, 50-199.9 cm and > 200 cm)
k. regeneration summary (seedlings, regeneration and saplings), diameter class distribution.

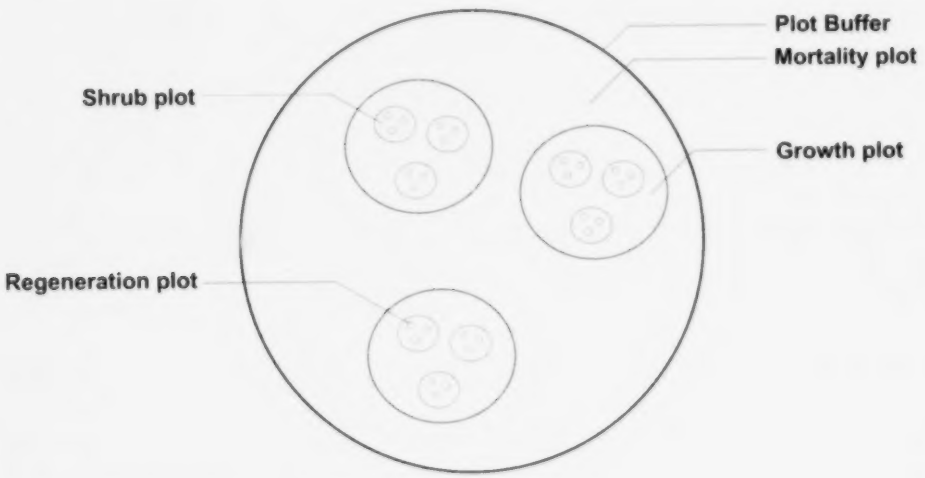

Figure 2.1. Growth and yield plot layout.

Forest Stratification

Based on the 'forest unit' attribute for each Region (Northwest and Northeast) we grouped each PSP into one of 6 classes including: a) upland conifer, b) lowland conifer, c) deciduous, d) mixed deciduous, e) Great Lakes St. Lawrence Pines and f) mixed conifer (Tables 2.1 and 2.2).

Table 2.1. Northwest standard forest units and class assignment.

Northwest Forest Units	Classes
Balsam Fir Dominated (BfDom)	Upland Conifer
White Birch Dominated (BwDom)	Deciduous
Conifer Mixedwood (ConMx)	Conifer Mixedwood
Hardwood Mixedwood (HrdMw)	Deciduous Mixedwood
Hardwood Dominated (HrDom)	Deciduous
Other Hardwoods (OthHd)	Deciduous
Jack Pine Deep (PjDee)	Upland Conifer
Jack Pine Mixed (PjMx1)	Upland Conifer
Jack Pine Shallow (PjSha)	Upland Conifer
Poplar Deep (PoDee)	Deciduous
Poplar Shallow (PoSha)	Deciduous
Red Pine Dominated (PrDom)	Great Lakes St. Lawrence Pines
Red – White Pine Mixed (PrwMx)	Conifer Mixedwood
White Pine Dominated (PwDom)	Great Lakes St. Lawrence Pines
Black Spruce Deep (SbDee)	Upland Conifer
Black Spruce Lowland (SbLow)	Lowland Conifer
Spruce Mixedwood (SbMx1)	Upland Conifer
Black Spruce Shallow (SbSha)	Upland Conifer

Table 2.2. Northeast standard forest units and class assignment.

Northeast Forest Units	Classes
White Birch (BW1)	Deciduous
Conifer Lowland (LOWCON)	Lowland Conifer
Lowland Hardwood (LH1)	Deciduous
Conifer Mixedwood (MW1)	Mixed Conifer
Conifer Mixedwood (MW2)	Mixed Conifer
Jack Pine (PJ1)	Upland Conifer
Jack Pine (PJ2)	Upland Conifer
Poplar (PO1)	Deciduous
Red Pine (PR1)	Great Lakes St. Lawrence Pines
Red Pine Mixedwood (PRW)	Conifer Mixedwood
White Pine (PW1)	Great Lakes St. Lawrence Pines
Black Spruce (SB1)	Lowland Conifer
Spruce – Fir (SF1)	Upland Conifer
Spruce (SP1)	Upland Conifer
Tolerant Hardwoods (TH1)	Deciduous

Measurements from 741 permanent sample plots (PSP) were summarized and 'forest attribute look-up tables' were created for;

i. Percent crown closure,
ii. Total volume down wood debris,
iii. Stand height and
iv. Snags (1-10 cm, 11-20 cm, 21-30 cm, 31-40 cm, 41-50 cm and >50 cm)

We assigned either 'North' or 'South' to each permanent sample plot depending on the Ecoregion it was located in (Table 2.3). This decision was suggested by the Landscape Book Boreal Science Team (April 2004).

We created point scatter plots of each attribute (crown closure, snags, down woody debris and height) by age. Next, a 2nd order polynomial was estimated and fitted to each point scatter plot and subsequent equations and look-up tables were generated. Many of the plots had few data points. Similarly, many of the scatter plots were highly variable. We reviewed each plot and look-up table and created subsequent 'expert opinion' plots and look-up tables.

RESULTS

Habitat element curves were cast as look-up tables, where points were separated by 1-year intervals. Separate curves were created for south upland conifer (SUC), north upland conifer (NUC), south lowland conifer (SLC), north lowland conifer (NLC), south deciduous (SD), north deciduous (ND), south deciduous mixedwood (SDM), north deciduous mixedwood (NDM), south Great Lakes St. Lawrence pines (SGLSLP), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM) and south conifer mixedwood (SCM).

Percent crown closure (Table 2.4; Fig. 2.2) reveals different patterns among strata, and closure occurs most slowly in the northern Great Lakes St. Lawrence pines (NGLSLP). Patterns are generally more similar among strata for downed woody debris (DWD) (Table 2.5; Fig. 2.3) and mean stand height (Table 2.6; Fig. 2.4). The smallest diameter class of snags numerically dominated the snag curves, but this class has less biodiversity value than the larger classes (Table 2.7; Fig.2.5). Similar results for snag density are presented for other forest strata (Tables 2.8 – 2.16; Figs 2.6 – 2.14).

Table 2.3. Zone assigned to permanent sample plots within each ecoregion.

Ecoregion	Zone
3W	North
3E	North
4S	South
5S	South
4W	South
4E	South

DISCUSSION

We designed the look-up tables to be used within the Patchworks framework. Patchworks has deterministic succession which requires an exact proportion of a given forest unit to succeed into a new forest unit at a given time. When a forest unit succeeds to a new forest unit a new age and usually lower age is assigned to the polygon. For each forest attribute (i.e., crown closure, height, snags, downed wood debris), providing that the new post succession value (new FU @ new age) is lower than the pre-succession value (old FU @ succession age) the post-succession values should be used. In the cases where the post-succession value is higher than the pre-succession value the stand should enter the post succession curve at the highest age where the values of the old forest unit and new forest unit are the same.

In cases where no succession occurs past the extent of the look-up tables (140 years or 240 for pines) the last values in the look-up table should be used.

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Table 2.4. Percent (%) crown closure look-up table including south upland conifer (SUC), north upland conifer (NUC), south lowland conifer (SLC), north lowland conifer (NLC), south deciduous (SD), north deciduous (ND), south deciduous mixedwood (SDM), north deciduous mixedwood (NDM), south Great Lakes St. Lawrence pines (SGLSLP), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM) and south conifer mixedwood (SCM).

Age	SUC	NUC	SLC	NLC	SD	ND	SDM	NDM*	SGLSLP	NGLSLP	NCM	SCM*
0	0	0	0	0	0	0	0	0	0	0	0	0
10	11.057	12.22	7.342	6.23	15.074	15.148	15.171	15.171	7.354	10.512	10.438	10.438
20	20.494	22.74	13.904	11.88	27.768	28.116	30.114	30.114	14.168	20.264	19.756	19.756
30	28.311	31.56	19.686	16.95	38.082	38.904	44.829	44.829	20.442	29.256	27.954	27.954
40	34.508	38.68	24.688	21.44	46.016	47.512	59.316	59.316	26.176	37.488	35.032	35.032
50	39.085	44.1	28.91	25.35	51.57	53.94	73.575	73.575	31.37	44.96	40.99	40.99
60	42.042	47.82	32.352	28.68	54.744	58.188	73.575	73.575	36.024	51.672	45.828	45.828
70	43.379	49.84	35.014	31.43	55.538	60.256	63	63	40.138	57.624	49.546	49.546
80	43.096	50.16	36.896	33.6	53.952	60.144	53	53	43.712	62.816	52.144	52.144
90	41.193	48.78	37.998	35.19	49.986	57.852	43	43	46.746	67.248	53.622	53.622
100	37.67	45.7	38.32	36.2	43.64	53.38	33	33	49.24	70.92	53.98	53.98
110	32.527	40.92	37.862	36.63	43.64	46.728	23	23	51.194	73.832	53.98	53.98
120	25.764	34.44	36.624	36.48	43.64	46.728	23	23	52.608	75.984	53.98	53.98
130	25.764	34.44	34.606	35.75	43.64	46.728	23	23	53.482	77.376	53.98	53.98
140	25.764	34.44	31.808	34.44	43.64	46.728	23	23	53.816	78.008	53.98	53.98
150									53.61	77.88		
160									52.864	76.992		
170									51.578	75.344		
180									49.752	72.936		
190									47.386	69.768		
200									44.48	65.84		
210									41.034	61.152		
220									37.048	55.704		
230									32.522	49.496		
240									27.456	42.528		

* Data for north deciduous mixedwood (NDM) were not available and we have used south deciduous mixedwood as an estimate. Similarly, data for south conifer mixedwood (SCM) were not available and we have used north conifer mixedwood as an estimate.

Table 2.5. Downed woody debris (m^3/hectare) look-up table including south upland conifer (SUC), north upland conifer (NUC), south lowland conifer (SLC), north lowland conifer (NLC), south deciduous (SD), north deciduous (ND), south deciduous mixedwood (SDM), north deciduous mixedwood (NDM), south Great Lakes St. Lawrence pines (SGLSLP), north Great Lakes St. Lawrence pines (NGLSLP), north conifer mixedwood (NCM) and south conifer mixedwood (SCM).

Age	SUC	NUC	SLC	NLC	SD	ND	SDM	NDM*	SGLSL	NGLSL	NCM	SCM*
0	0	0	0	0	0	0	0	0	0	0	0	0
10	2.088	2.088	2.088	2.088	3.615	4.017	2.829	2.829	2.872	3.508	2.089	2.089
20	4.016	4.016	4.016	4.016	6.91	7.654	5.438	5.438	5.584	6.816	4.018	4.018
30	5.784	5.784	5.784	5.784	9.885	10.911	7.827	7.827	8.136	9.924	5.787	5.787
40	7.392	7.392	7.392	7.392	12.54	13.788	9.996	9.996	10.528	12.832	7.396	7.396
50	8.84	8.84	8.84	8.84	14.875	16.285	11.945	11.945	12.76	15.54	8.845	8.845
60	10.128	10.128	10.128	10.128	16.89	18.402	13.674	13.674	14.832	18.048	10.134	10.134
70	11.256	11.256	11.256	11.256	18.585	20.139	15.183	15.183	16.744	20.356	11.263	11.263
80	12.224	12.224	12.224	12.224	19.96	21.496	16.472	16.472	18.496	22.464	12.232	12.232
90	13.032	13.032	13.032	13.032	21.015	22.473	17.541	17.541	20.088	24.372	13.041	13.041
100	13.68	13.68	13.68	13.68	21.75	23.07	18.39	18.39	21.52	26.08	13.69	13.69
110	14.168	14.168	14.168	14.168	22.165	23.287	19.019	19.019	22.792	27.588	14.179	14.179
120	14.496	14.496	14.496	14.496	22.26	23.287	19.428	19.428	23.904	28.896	14.508	14.508
130	14.664	14.664	14.664	14.664	22.035	23.287	19.617	19.617	24.856	30.004	14.677	14.677
140	14.672	14.672	14.672	14.672	22.035	23.287	19.617	19.617	25.648	30.912	14.686	14.686
150									26.28	31.62		
160									26.752	32.128		
170									27.064	32.436		
180									27.216	32.544		
190									27.208	32.452		
200									27.04	32.16		
210									26.712	31.668		
220									26.224	30.976		
230									25.576	30.084		
240									24.768	28.992		

* Data for north deciduous mixedwood (NDM) were not available and we have used south deciduous mixedwood as an estimate. Similarly, data for south conifer mixedwood (SCM) were not available and we have used north conifer mixedwood as an estimate.

Table 2.6. Mean stand height (m/hectare) look-up table including south upland conifer (SUC), north upland conifer (NUC), south lowland conifer (SLC), north lowland conifer (NLC), south deciduous (SD), north deciduous (ND), south deciduous mixedwood (SDM), north deciduous mixedwood (NDM), south Great Lakes St. Lawrence pines (SGLSLP), north Great Lakes St. Lawrence pines (NGLSLP), north conifer mixedwood (NCM) and south conifer mixedwood (SCM).

Age	SUC	NUC	SLC	NLC	SD	ND	SDM	NDM*	SGLSLP	NGLSLP	NCM	SCM*
0	0	0	0	0	0	0	0	0	0	0	0	0
10	3.04	3.552	2.088	2.089	3.615	4.017	2.829	2.829	2.872	3.508	3.508	3.508
20	5.78	6.724	4.016	4.018	6.91	7.654	5.438	5.438	5.584	6.816	6.816	6.816
30	8.22	9.516	5.784	5.787	9.885	10.911	7.827	7.827	8.136	9.924	9.924	9.924
40	10.36	11.928	7.392	7.396	12.54	13.788	9.996	9.996	10.528	12.832	12.832	12.832
50	12.2	13.96	8.84	8.845	14.875	16.285	11.945	11.945	12.76	15.54	15.54	15.54
60	13.74	15.612	10.128	10.134	16.89	18.402	13.674	13.674	14.832	18.048	18.048	18.048
70	14.98	16.884	11.256	11.263	18.585	20.139	15.183	15.183	16.744	20.356	20.356	20.356
80	15.92	17.776	12.224	12.232	19.96	21.496	16.472	16.472	18.496	22.464	22.464	22.464
90	16.56	18.288	13.032	13.041	21.015	22.473	17.541	17.541	20.088	24.372	24.372	24.372
100	16.9	18.42	13.68	13.69	21.75	23.07	18.39	18.39	21.52	26.08	26.08	26.08
110	16.94	18.42	14.168	14.179	22.165	23.287	19.019	19.019	22.792	27.588	27.588	27.588
120	16.94	18.42	14.496	14.508	22.26	23.287	19.428	19.428	23.904	28.896	28.896	28.896
130	16.94	18.42	14.664	14.677	22.035	23.287	19.617	19.617	24.856	30.004	30.004	30.004
140	16.94	18.42	14.672	14.686	22.035	23.287	19.617	19.617	25.648	30.912	30.912	30.912
150									26.28	31.62		
160									26.752	32.128		
170									27.064	32.436		
180									27.216	32.544		
190									27.216	32.544		
200									27.216	32.544		
210									27.216	32.544		
220									27.216	32.544		
230									27.216	32.544		
240									27.216	32.544		

* Data for north deciduous mixedwood (NDM) were not available and we have used south deciduous mixedwood as an estimate. Similarly, data for south conifer mixedwood (SCM) were not available and we have used north conifer mixedwood as an estimate.

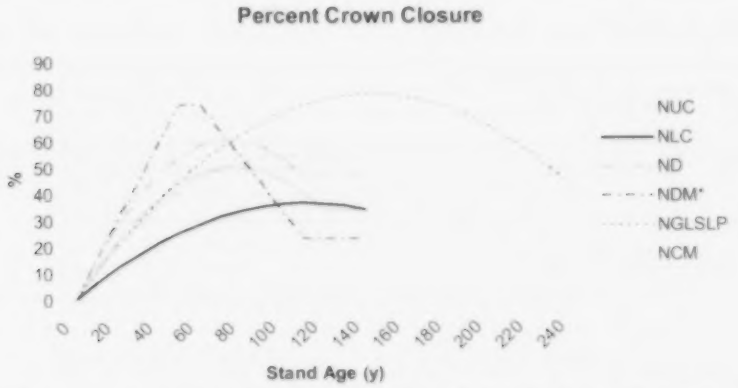

Figure 2.2. Percent (%) crown closure for the north forest types including north upland conifer (NUC), north lowland conifer (NLC), north deciduous (ND), north deciduous mixedwood (NDM), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM).

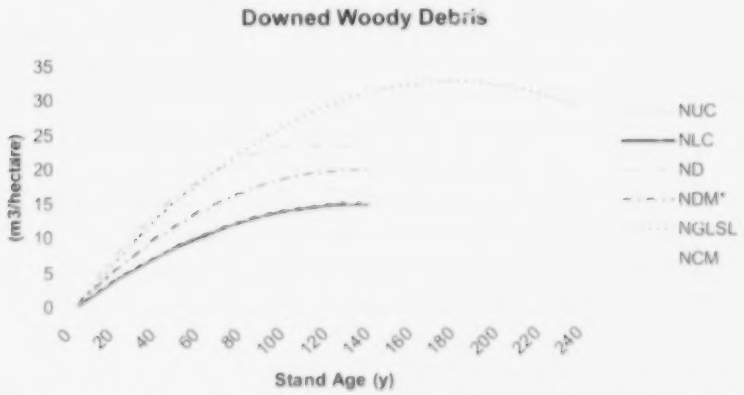

Figure 2.3. Downed woody debris (m^3/hectare) for the north forest types including north upland conifer (NUC), north lowland conifer (NLC), north deciduous (ND), north deciduous mixedwood (NDM), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM).

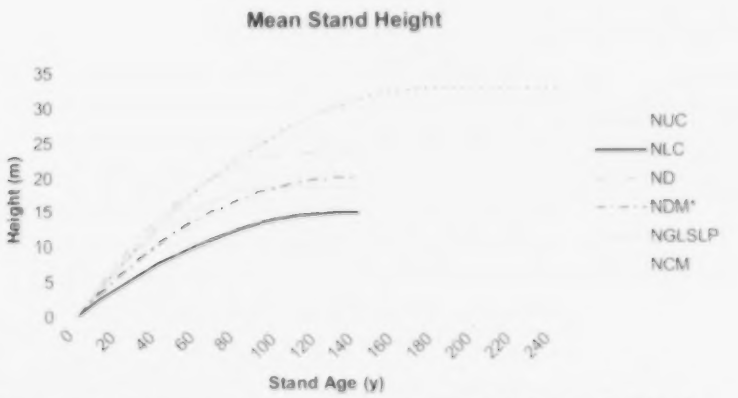

Figure 2.4. Mean stand height (m/hectare) for the north forest types including north upland conifer (NUC), north lowland conifer (NLC), north deciduous (ND), north deciduous mixedwood (NDM), north Great Lakes St. Lawrence pines (NGLSLP) and north conifer mixedwood (NCM).

* Data for north deciduous mixedwood (NDM) were not available and we have used south deciduous mixedwood as an estimate.

Table 2.7. Number of snags (#/ha) in the south upland conifer class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	92.269	2.497	4.367	0.043	0.357	0.034
20	171.838	4.674	8.394	0.166	0.774	0.128
30	238.707	6.531	12.081	0.369	1.251	0.282
40	292.873	8.068	15.428	0.652	1.788	0.496
50	334.345	9.285	18.435	1.015	2.385	0.77
60	363.114	10.182	21.102	1.458	3.042	1.104
70	379.183	10.759	23.429	1.981	3.759	1.498
80	382.552	11.016	25.416	2.584	4.536	1.952
90	373.221	10.953	27.063	3.267	5.373	2.466
100	351.19	10.57	28.37	4.03	6.27	3.04
110	316.459	9.867	29.337	4.873	7.227	3.674
120	269.028	8.844	29.964	5.796	8.244	4.368
130	208.897	7.501	30.251	6.799	9.321	5.122
140	136.066	5.838	30.198	7.882	10.458	5.936

Table 2.8. Number of snags (#/ha) in the north upland conifer class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	129.16	29.17	2.018	0.428	0.089	0.114
20	238.02	56.44	4.556	0.856	0.172	0.228
30	326.58	81.81	7.614	1.286	0.249	0.340
40	394.84	105.28	11.192	1.718	0.32	0.450
50	442.8	126.85	15.29	2.15	0.385	0.56
60	470.46	146.52	19.908	2.584	0.444	0.668
70	477.82	164.29	25.046	3.018	0.497	0.776
80	464.88	180.16	30.704	3.454	0.544	0.882
90	431.64	194.13	36.882	3.892	0.585	0.986
100	378.1	206.2	43.58	4.33	0.62	1.09
110	304.26	216.37	50.798	4.770	0.649	1.192
120	210.12	224.64	58.536	5.210	0.672	1.294
130	95.68	231.01	66.794	5.652	0.689	1.394
140	95.68	235.48	75.572	6.096	0.7	1.492

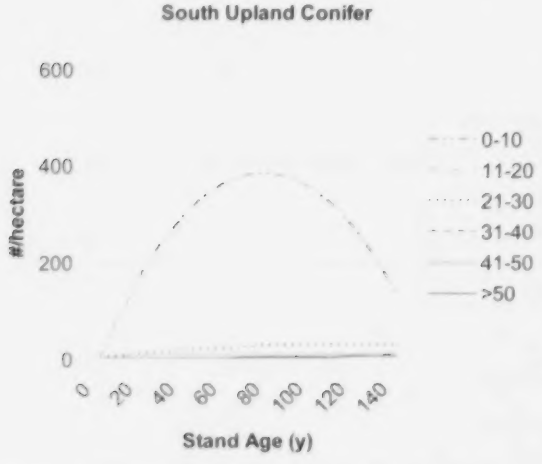

Figure 2.5. Number of snags (#/ha) in the south upland conifer class. Numbers of snags presented in 10 centimeter size classes.

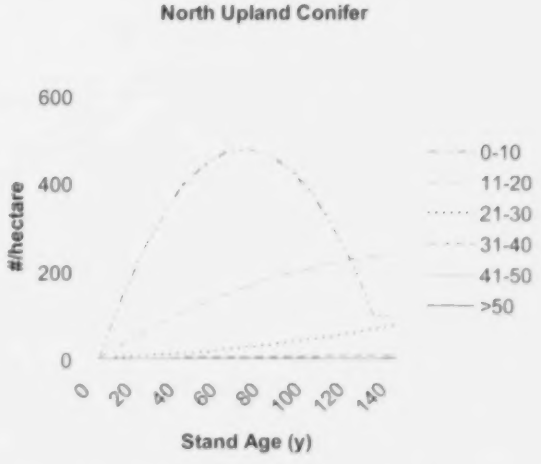

Figure 2.6. Number of snags (#/ha) in the north upland conifer class. Numbers of snags presented in 10 centimeter size classes.

Table 2.9. Number of snags (#/ha) in the south lowland conifer class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	71.365	17.739	2.444	0.15	0.096	0.041
20	137.17	34.878	4.648	0.28	0.179	0.078
30	197.415	51.417	6.612	0.39	0.251	0.111
40	252.1	67.356	8.336	0.48	0.31	0.14
50	301.225	82.695	9.82	0.55	0.358	0.165
60	344.79	97.434	11.064	0.6	0.393	0.186
70	382.795	111.573	12.068	0.63	0.417	0.203
80	415.24	125.112	12.832	0.64	0.428	0.216
90	442.125	138.051	13.356	0.63	0.428	0.225
100	463.45	150.39	13.64	0.6	0.415	0.23
110	479.215	162.129	13.684	0.55	0.391	0.231
120	489.42	173.268	13.488	0.48	0.354	0.228
130	494.065	183.807	13.052	0.39	0.306	0.221
140	493.15	193.746	12.376	0.28	0.245	0.21

Table 2.10. Number of snags (#/ha) in the north lowland conifer class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	70.23	9.11	0.136	0	0	0.002
20	133.02	18.02	0.392	0	0	0.004
30	188.37	26.73	0.768	0	0	0.007
40	236.28	35.24	1.264	0	0	0.010
50	276.75	43.55	1.88	0	0	0.013
60	309.78	51.66	2.616	0	0	0.016
70	335.37	59.57	3.472	0	0	0.019
80	353.52	67.28	4.448	0	0	0.022
90	364.23	74.79	5.544	0	0	0.026
100	367.5	82.1	6.76	0	0	0.03
110	363.33	89.21	8.096	0.22	0	0.034
120	351.72	96.12	9.552	0.72	0	0.038
130	332.67	102.83	11.128	1.3	0.013	0.043
140	306.18	109.34	12.824	1.96	0.154	0.048

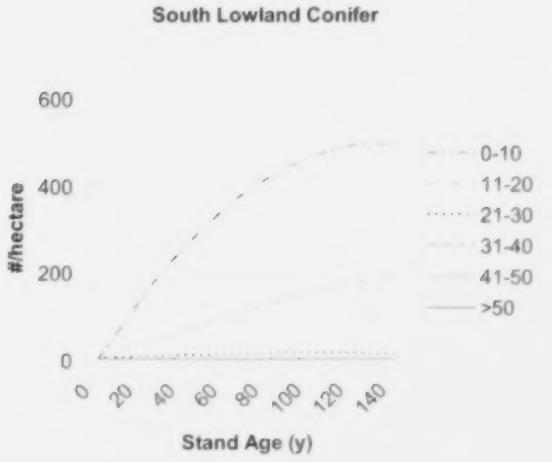

Figure 2.7. Number of snags (#/ha) in the south lowland conifer class. Numbers of snags presented in 10 centimeter size classes

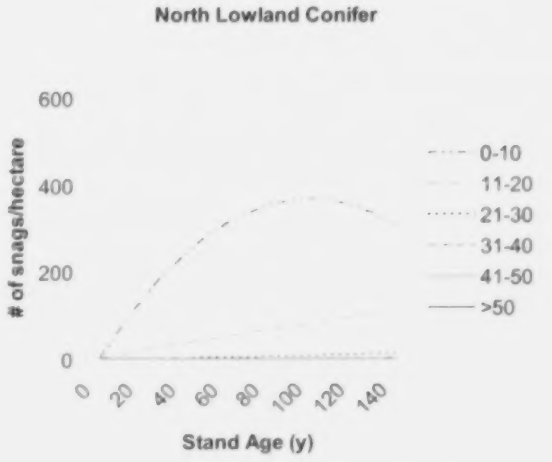

Figure 2.8. Number of snags (#/ha) in the north lowland conifer class. Numbers of snags presented in 10 centimeter size classes.

Table 2.11. Number of snags (#/ha) in the south deciduous and south deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	92.36	34.606	5.099	0.178	0.408	0.154
20	163.86	64.712	10.078	0.596	0.956	0.268
30	214.5	90.318	14.937	1.254	1.644	0.342
40	244.28	111.424	19.676	2.152	2.472	0.376
50	253.2	128.03	24.295	3.29	3.44	0.37
60	241.26	140.136	28.794	4.668	4.548	0.324
70	208.46	147.742	33.173	6.286	5.796	0.238
80	154.8	150.848	37.432	8.144	7.184	0.112
90	80.28	149.454	41.571	10.242	8.712	0.112
100	0	143.56	45.59	12.58	10.38	0.112
110	0	133.166	49.489	15.158	12.188	0.112
120	0	118.272	53.268	17.976	14.136	0.112
130	0	98.878	56.927	21.034	16.224	0.112
140	0	74.984	60.466	24.332	18.452	0.112

* Data were not available in the south deciduous mixed class and we have assumed that the deciduous is approximately the same.

Table 2.12. Number of snags (#/ha) in the north deciduous and north deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	129.16	32.856	1.544	0.706	0.113	0.072
20	238.02	61.272	3.848	1.312	0.21	0.154
30	326.58	85.248	6.912	1.818	0.291	0.246
40	394.84	104.784	10.736	2.224	0.356	0.348
50	442.8	119.88	15.32	2.53	0.405	0.46
60	470.46	130.536	20.664	2.736	0.438	0.582
70	477.82	136.752	26.768	2.842	0.455	0.714
80	464.88	138.528	33.632	2.848	0.456	0.856
90	431.64	135.864	41.256	2.754	0.441	1.008
100	378.1	128.76	49.64	2.56	0.41	1.17
110	304.26	117.216	58.784	2.266	0.363	1.342
120	210.12	101.232	68.688	1.872	0.3	1.524
130	95.68	80.808	79.352	1.378	0.221	1.716
140	95.68	55.944	90.776	0.784	0.126	1.918

* Data were not available in the north deciduous mixed class and we have assumed that the deciduous is approximately the same.

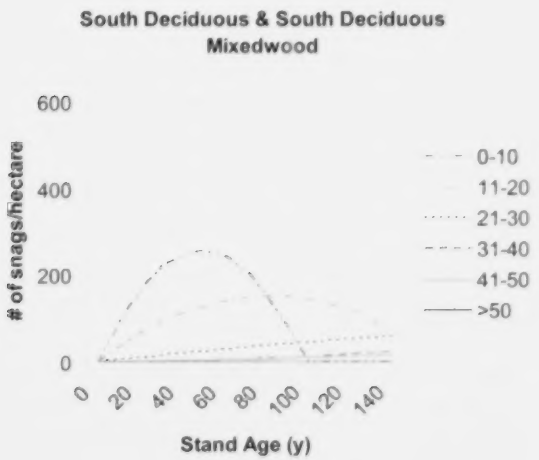

Figure 2.9. Number of snags (#/ha) in the south deciduous and south deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes. * Data were not available in the south deciduous mixed class and we have assumed that the deciduous is approximately the same.

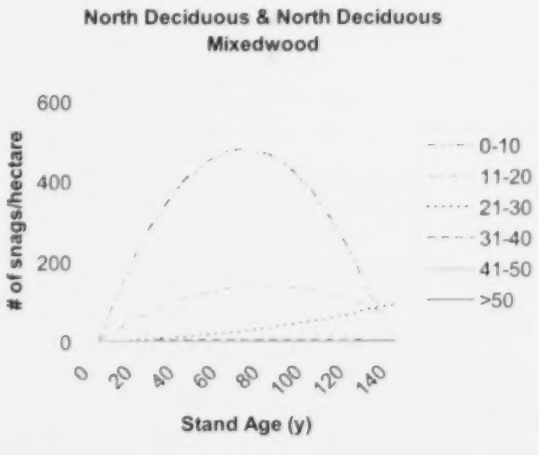

Figure 2.10. Number of snags (#/ha) in the north deciduous and north deciduous mixedwood* class. Numbers of snags presented in 10 centimeter size classes. *Data were not available in the north deciduous mixed class and we have assumed that the deciduous is approximately the same.

Table 2.13. Number of snags (#/ha) in the south Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	71.365	17.742	9.55	1.9	0.695	-0.1
20	137.17	34.344	18.36	3.66	1.39	-0.16
30	197.415	49.806	26.43	5.28	2.085	-0.18
40	252.1	64.128	33.76	6.76	2.78	-0.16
50	301.225	77.31	40.35	8.1	3.475	-0.1
60	344.79	89.352	46.2	9.3	4.17	0
70	382.795	100.254	51.31	10.36	4.865	0.14
80	415.24	110.016	55.68	11.28	5.56	0.32
90	442.125	118.638	59.31	12.06	6.255	0.54
100	463.45	126.12	62.2	12.7	6.95	0.8
110	479.215	132.462	64.35	13.2	7.645	1.1
120	489.42	137.664	65.76	13.56	8.34	1.44
130	494.065	141.726	66.43	13.78	9.035	1.82
140	493.15	144.648	66.36	13.86	9.73	2.24
150	486.675	146.43	65.55	13.8	10.425	2.7
160	474.64	147.072	64	13.6	11.12	3.2
170	457.045	146.574	61.71	13.26	11.815	3.74
180	433.89	144.936	58.68	12.78	12.51	4.32
190	405.175	142.158	54.91	12.16	13.205	4.94
200	370.9	138.24	50.4	11.4	13.9	5.6
210	331.065	133.182	45.15	10.5	14.595	6.3
220	285.67	126.984	39.16	9.46	15.29	7.04
230	234.715	119.646	32.43	8.28	15.985	7.82
240	178.2	111.168	24.96	6.96	16.68	8.64
250	116.125	101.55	16.75	5.5	17.375	9.5

Table 2.14. Number of snags (#/ha) in the north Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	47.29	12.76	3.279	1.801	0.322	0.162
20	91.3	24.56	6.338	3.541	0.744	0.314
30	132.03	35.4	9.177	5.222	1.266	0.456
40	169.48	45.28	11.796	6.842	1.888	0.588
50	203.65	54.2	14.195	8.403	2.61	0.71
60	234.54	62.16	16.374	9.903	3.432	0.822
70	262.15	69.16	18.333	11.344	4.354	0.924
80	286.48	75.2	20.072	12.724	5.376	1.016
90	307.53	80.28	21.591	14.045	6.498	1.098
100	325.3	84.4	22.89	15.305	7.72	1.17
110	339.79	87.56	23.969	16.506	9.042	1.232
120	351	89.76	24.828	17.646	10.464	1.284
130	358.93	91	25.467	18.727	11.986	1.326
140	363.58	91.28	25.886	19.747	13.608	1.358
150	364.95	90.6	26.085	20.708	15.33	1.38
160	363.04	88.96	26.064	21.608	17.152	1.392
170	357.85	86.36	25.823	22.449	19.074	1.394
180	349.38	82.8	25.362	23.229	21.096	1.386
190	337.63	78.28	24.681	23.950	23.218	1.368
200	322.6	72.8	23.78	24.61	25.44	1.34
210	304.29	66.36	22.659	25.211	27.762	1.302
220	282.7	58.96	21.318	25.751	30.184	1.254
230	257.83	50.6	19.757	26.232	32.706	1.196
240	229.68	41.28	17.976	26.652	35.328	1.128
250	198.25	31	15.975	27.013	38.05	1.05

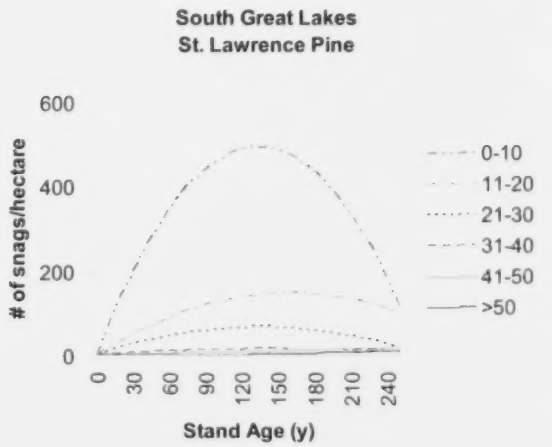

Figure 2.11. Number of snags (#/ha) in the south Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes.

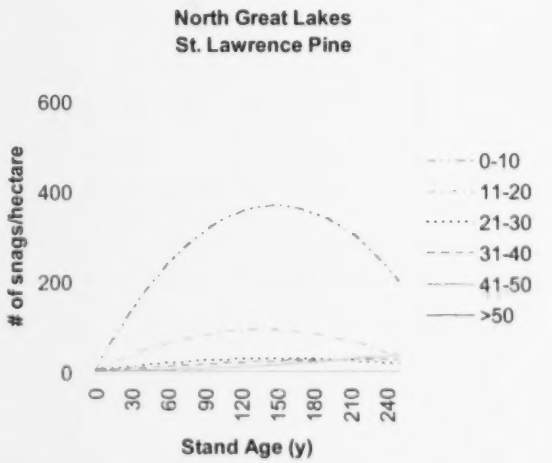

Figure 2.12. Number of snags (#/ha) in the north Great Lakes St. Lawrence pines class. Numbers of snags presented in 10 centimeter size classes.

Table 2.15. Number of snags (#/ha) in the south conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	120.82	27.112	0.869	3.05	0	0
20	220.08	51.084	2.618	6.94	0	0
30	297.78	71.916	5.247	11.67	0	0
40	353.92	89.608	8.756	17.24	0	0
50	388.5	104.16	13.145	23.65	0	0
60	401.52	115.572	18.414	30.9	0	0.06
70	392.98	123.844	24.563	38.99	0.224	0.21
80	362.88	128.976	31.592	47.92	0.656	0.4
90	311.22	130.968	39.501	57.69	1.188	0.63
100	238	129.82	48.29	68.3	1.82	0.9
110	143.22	125.532	57.959	79.75	2.552	1.21
120	26.88	118.104	68.508	92.04	3.384	1.56
130	0	107.536	79.937	105.17	4.316	1.95
140	0	93.828	92.246	119.14	5.348	2.38

Table 2.16. Number of snags (#/ha) in the north conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes.

Age	0-10	11-20	21-30	31-40	41-50	>50
0	0	0	0	0	0	0
10	91.57	24.207	5.568	0.05	0.171	0
20	168.28	45.234	10.596	0.18	0.322	0
30	230.13	63.081	15.084	0.39	0.453	0
40	277.12	77.748	19.032	0.68	0.564	0
50	309.25	89.235	22.44	1.05	0.655	0
60	326.52	97.542	25.308	1.5	0.726	0.06
70	328.93	102.669	27.636	2.03	0.777	0.21
80	316.48	104.616	29.424	2.64	0.808	0.4
90	289.17	103.383	30.672	3.33	0.819	0.63
100	247	98.97	31.38	4.1	0.81	0.9
110	189.97	91.377	31.548	4.95	0.781	1.21
120	118.08	80.604	31.176	5.88	0.732	1.56
130	31.33	66.651	30.264	6.89	0.663	1.95
140	0	49.518	28.812	7.98	0.574	2.38

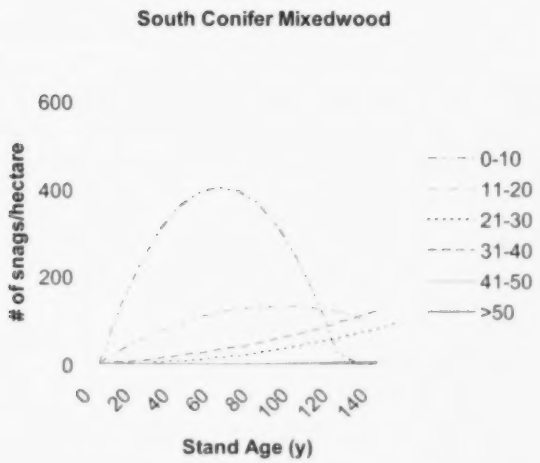

Figure 2.13. Number of snags (#/ha) in the south conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes.

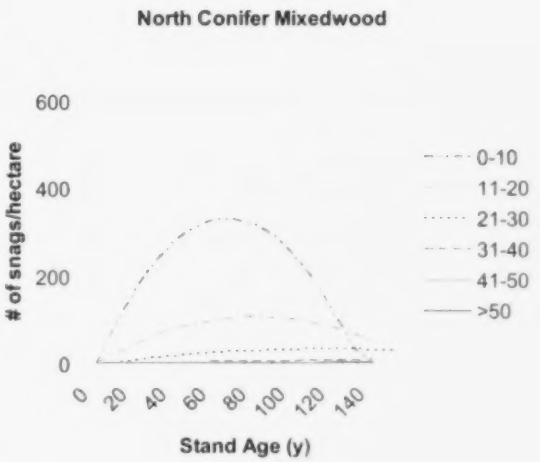

Figure 2.14. Number of snags (#/ha) in the north conifer mixedwood class. Numbers of snags presented in 10 centimeter size classes.

Chapter 3

Patchworks Integration & Initial Model Comparison

Robert Rempel, PhD[1], Janet Jackson, MScF[1] and Tom Moore MScF[2]

[1]Ontario Ministry of Natural Resources

[2]Spatial Planning Systems

INTRODUCTION

Integration of the habitat element curve models with a forest projection model is necessary to "scale-up" the stand level predictions to the landscape level and to project habitat conditions over time. As a result of this integration, small differences in stand-level models may be manifest as rather dramatic differences across space and time. To evaluate and compare the predicted habitat patterns resulting from two different habitat element curves models, we integrated the modeled HEC relationships from both the FORECAST model and EMPIRICAL model into the spatial harvest scheduler, Patchworks (Spatial Planning Systems 2008). Patchworks' modeling environment allows for easy integration of stand development models through lookup tables.

METHODS

Two approaches were used to integrate the HEC model with the spatial projection model. In the first case a translator program was developed to convert output from the FORECAST model into Patchworks XML format and lookup tables. This format is based on existing non-proprietary standards. Although the purpose is primarily to acquire non-timber characteristics suitable for habitat assessment, the translator was designed to extract the full suite of FORECAST stand-level predictions, and make them available at a whole-forest level within Patchworks. Patchworks XML lookup tables were also created for the EMPIRICAL model. A second approach to model integration involved the spatial analysis program LSL (Kushneriuk and Rempel 2007), where HEC tables were defined in LSL and the lookups applied to projected GIS files that were output from Patchworks and then imported to LSL.

Variable names referring to the FORECAST model are all preceded with an f (e.g., favtopht for average top height), and those without an f are variables from the EMPIRICAL model developed by Elkie et al. (e.g. ht). Patchworks attribute data is from a subsample (1000) of stands at simulation years 0 and 20. FORECAST curves have 2 sets for each variable: one for natural stand origin and the other for managed stands, whereas the EMPIRICAL model has only a single curve that applies to both managed and unmanaged conditions.

A series of simulation runs was performed to compare the 'FORECAST' indicators to PSP and other Ontario datasets. Field testing of the models is currently in progress, and will be reported in a subsequent report.

RESULTS

Class Groupings and Model Attributes

The analysis units (AU) used for the FORECAST model were designed to resemble the empirical model groupings (analysis units) used in the Landscape Guide project (Table 3.1). The main difference was that the GLSL pines group used in the empirical model was aggregated with the Upland pines group in the FORECAST model.

The two models produced similar attributes, but with the main differences being the FORECAST model provides more detail for snag attributes based on overstory species, and estimates the number of downed logs (Table 3.2). Both models used Plonski curves for estimating stand volume, but the FORECAST model estimates volume based on growth models and a taper function, and calibrates the model based on Plonski curves.

Comparison of habitat element (variable) predictions

Tree Height

The shape of the black spruce height curves is similar among models, but the EMPIRICAL model flattens at age 90 (Fig. 3.1). This modification of the empirically derived growth curve was based on expert opinion. This illustrates the hybrid nature of both models. In the case of the FORECAST model, the shape of the curve is based on well defined growth processes, but calibrated to Ontario PSP data. In contrast, the EMPIRICAL model is initially derived from the PSP data, but modified based on expert opinion. The curve for trembling aspen (Fig. 3.2) is consistently lower throughout the EMPIRICAL model.

Table 3.1. Class relationships between the process-based (FORECAST) and empirical-based habitat element curve (HEC) strata.

No.	Analysis Unit	Curve ID	FORECAST Class Grouping	Empirical Class Grouping
1	BfD	110	Upland Conifer	Upland Conifer
2	BfM	110	Upland Conifer	Upland Conifer
3	BwD	107	Deciduous	Deciduous
4	BwM	107	Deciduous	Deciduous
5	CMxD	105	Conifer Mixedwood	Conifer Mixedwood
6	CMxM	104	Conifer Mixedwood	Conifer Mixedwood
7	CMxW	104	Conifer Mixedwood	Conifer Mixedwood
8	HMxD	109	Deciduous Mixedwood	Deciduous Mixedwood
9	HMxM	109	Deciduous Mixedwood	Deciduous Mixedwood
10	HwMz	106	Deciduous	Deciduous
11	HwR	106	Deciduous	Deciduous
12	OCLo	108	Upland Conifer	Lowland Conifer
13	OtHd	107	Deciduous	Deciduous
14	PjD	111	Upland Conifer	Upland Conifer
15	PjM	111	Upland Conifer	Upland Conifer
16	PjMx	111	Upland Conifer	Upland Conifer
17	PjP	108	Upland Conifer	Upland Conifer
18	PoD	106	Deciduous	Deciduous
19	PoM	106	Deciduous	Deciduous
20	PrDo	111	Upland Conifer	GLSL Pines
21	SMxD	105	Conifer Mixedwood	Upland Conifer
22	SMxM	104	Conifer Mixedwood	Upland Conifer
23	SbD	101	Upland Conifer	Upland Conifer
24	SbL	103	Lowland Conifer	Lowland Conifer
25	SbM	102	Upland Conifer	Upland Conifer
26	PwDo	102	Upland Conifer	GLSL Pines

Down Wood Debris

The down woody debris model differs between the two models, and in general, the FORECAST model predicts more DWD than the EMPIRICAL model (Figs. 3.3 and 3.4). The PSP data set has considerable zero-estimate records for DWD, even for older stands, and these records pull down the estimate of DWD. An alternative estimated curve is given in Fig. 3.4 to illustrate how removal of zero-records may influence the empirically estimated curve. Also, the FORECAST model is more complex because for some analysis units (AUs, Table 1.4 & 1.5) the predictions over time are strongly unimodal in shape (Fig. 3.3). Overall the relative spatial distribution of predicted DWD differs among models, but there are also zones of similarity between models (Fig. 3.5).

Snags

The FORECAST snag model assumes fire origin, so numerous snags are left in the early years for the natural origin stands, but this is not so for the EMPIRICAL model. This effect is especially prevalent in the Patchworks Year 0 runs, as most stands are (incorrectly) assumed to be natural origin at the start of the run. By Year 20, many

Table 3.2. Comparison of forest attributes for process-based (FORECAST) versus empirical based models.

Forest Attributes	FORECAST	Empirical
Average Stand Height (m)	**M**	**M**
Total number of Snags (all dbh sizes)	M	M
Total number of Conifer Snags > 20 cm dbh	**M**	**M**
Total number of Hardwood Snags > 20 cm dbh	M	M
Crown Closure		**M**
Down Wood Volume (m^3/ha)	M (P)	P
Black Spruce Volume (m^3/ha)	**M (P)**	**P**
Jack Pine Volume (m^3/ha)	M (P)	P
Balsam fir Volume (m^3/ha)	**M (P)**	**P**
Trembling Aspen Volume (m^3/ha)	M (P)	P
White Birch Volume (m^3/ha)	**M (P)**	**P**
Total number of Logs (all dbh sizes)	M	
Total number of Conifer Logs > 20 cm dbh	**M**	
Total number of Hardwood Logs > 20 cm dbh	M	
Total Shrub percent cover	**M**	
Number of Pj Stems (stems/ha)	M	P
Number of Sb Stems (stems/ha)	**M**	**P**
Number of Bf Stems (stems/ha)	M	P
Number of Po Stems (stems/ha)	**M**	**P**
Number of Bw Stems (stems/ha)	M	P
Total Number of Stems (stems/ha)	**M**	**P**

M = modeled

P = Values based on, or derived from Plonski's Growth & Yield curves

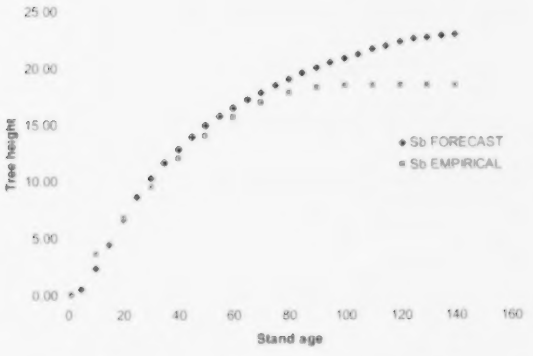

Figure 3.1. Comparative plot of black spruce growth curves.

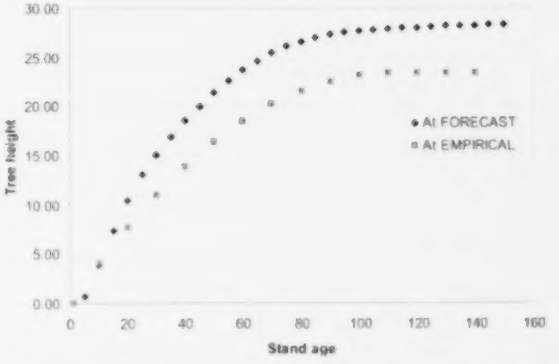

Figure 3.2. Comparative plot of trembling aspen growth curves.

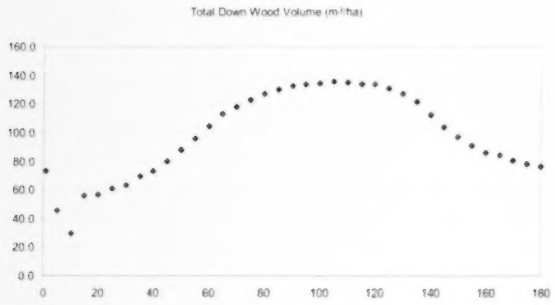

Figure 3.3. FORECAST curve for Total DWD, Black Spruce (AU 101, Table 1.4).

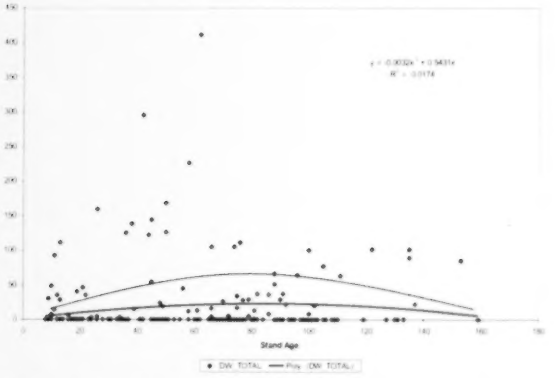

Figure 3.4. EMPIRICAL curve for total DWD, upland conifer analysis unit. Lower curve is the EMPIRICAL model. Upper curve is estimated model based on removal of zero-estimate date points.

stands are in managed condition, and this is reflected in the generally lower predicted snag density. Comparing the managed black spruce curve (AU 201, Table 1.5), the EMPIRICAL model predicts higher snag densities than the FORECAST model (Fig. 3.6) for upland conifer sites (conifer plus deciduous snags). In the FORECAST model, there is a drop in snag density at about year 70, presumably when the stand enters the mature stage, and the self-thinning stage has ended. Overall, the relative patterns of spatial dispersion for snags differ substantially between models (Fig.3.7)

DISCUSSION

Comparison of estimates between the two models requires careful evaluation of model outputs to ensure "apples are compared to apples." This exploratory analysis of model outputs revealed a number of initial inconsistencies that had to be addressed before valid comparisons could be made. For example, a simple calculation of mean top height from the FORECAST model was inappropriate for comparison with the EMPIRICAL model. In the case of black spruce analysis units, maximum top height of the black spruce working group species (as estimated in the FORECAST

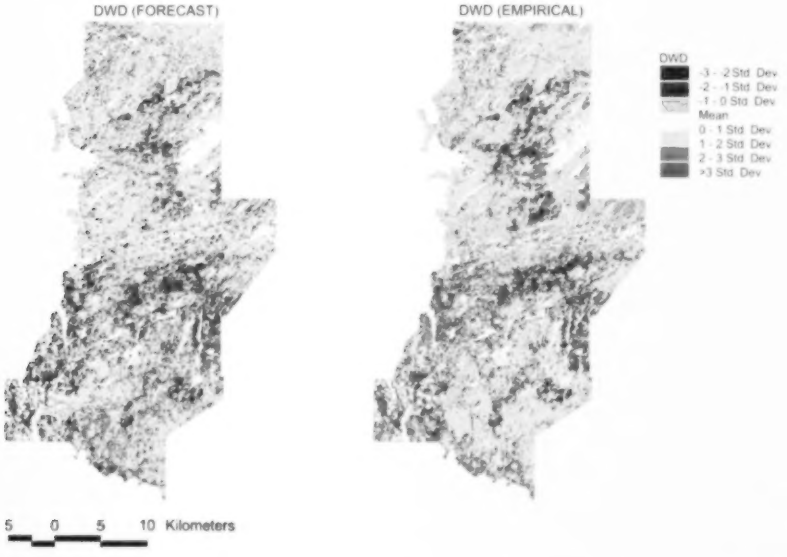

Figure 3.5. Comparative maps of down woody debris predictions (through Patchworks) based on EMPIRICAL versus FORECAST models. Each colour gradation represents a change of 1 standard deviation above or below the mean.

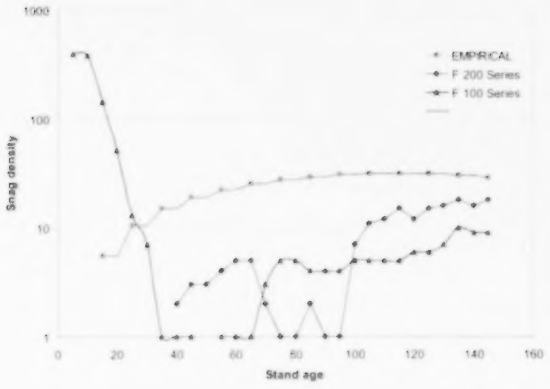

Figure 3.6. Northern upland conifer and upland black spruce models for all conifer snags >20 cm (FORECAST) and all snags in the 21-30 cm range (EMPIRICAL). F 200 series is FORECAST curve for managed stands, and 100 series is for natural origin stands. Scale is logarithmic, so 100 series density is almost 2 orders of magnitude higher at year 0.

model) should be compared to the expected height for the upland conifer analysis unit (as estimated in the EMPIRICAL model). In conifer mixedwood cases, the height should be estimated as the average height of jackpine, black spruce, and (perhaps) balsam fir.

Once the correct comparison is established, then difference in functional form of the models can be established. In the case of black spruce tree height, differences between the models occur only after year 80, and these differences are attributable to "expert" modification of the initial statistically estimated curve.

Field estimates of height will undoubtedly reveal errors in height, in part because site index is not used as a stratifying variable. There are 26 analysis units used for stratification, but for each analysis unit there will be variability in growth based on soil productivity at the site level. On average, however, the height curves should reflect growth patterns within an analysis unit.

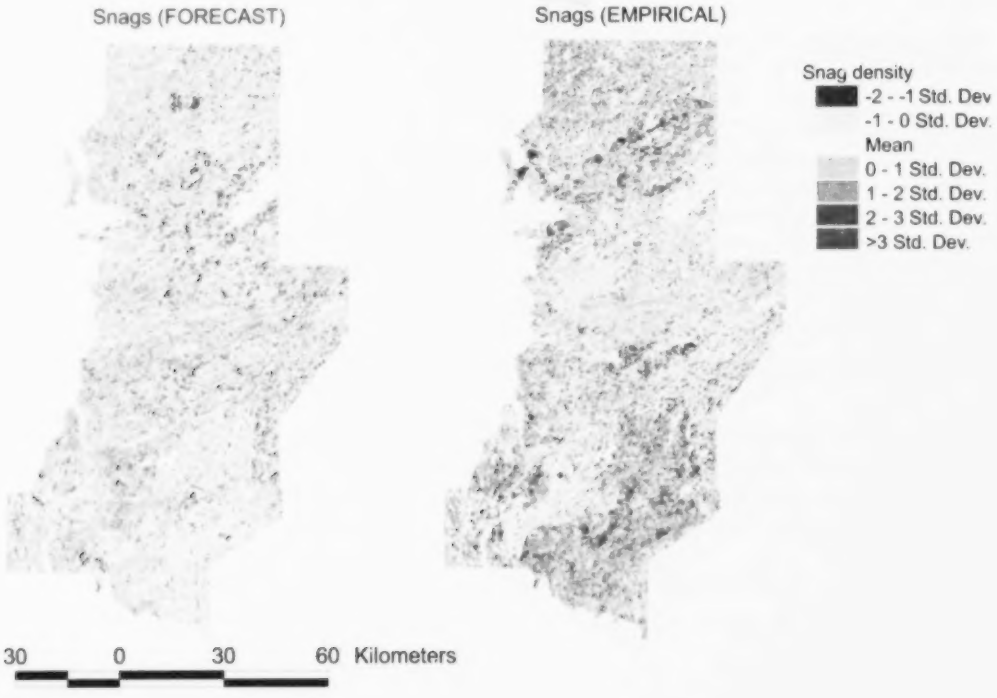

Figure 3.7. Comparative maps of snag density predictions (through Patchworks) based on EMPIRICAL (sn21-gt50) versus FORECAST (fallsnags) models. Each colour gradation represents a change of 1 standard deviation above or below the mean.

Down woody debris estimates differ substantially between the FORECAST and EMPIRICAL models. This is not surprising in that substantial environmental heterogeneity (i.e., noise) make it difficult to empirically estimate the true ecological relationship of this variable with stand age (i.e., signal). However, the differences in the model estimates appear to be more the result of a systematic bias than lack of precision in the data. The large number of zero-estimate records occurring in the PSP data set (e.g., Fig. 3.4) draws the model curve down for the EMPIRICAL model. An alternative approach for developing the EMPIRICAL model curves would be to remove zero-records from the analysis, and this would result in higher estimates of DWD volume. This might also result in greater similarity of the EMPIRICAL curves with FORECAST versions. Such an alternative EMPIRICAL model should be included for the field testing of model accuracy.

Snag density also differed among models. In particular, the FORECAST models differs substantially in the first 20 years between the natural origin (100 series) and managed origin (200 series) curves, as the natural origin stands begin with a high density of standing-snags following wildfire. Considering only the managed curves from FORECAST, the EMPIRICAL model predicts higher densities of snags than does the FORECAST model. As with the DWD estimates, snag density suffers from a low signal to noise ratio in most PSP data records, so there may be significant advantage gained from taking a process-oriented approach with this variable.

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Spatial Planning Systems, 2008. Pathworks. Deep River, Ontario.

Chapter 4

Comparative evaluation of model functional forms and external testing of model accuracy

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INTRODUCTION

Habitat element curves or models are simply hypotheses about relationships between and among variables, and are based on abstractions and generalizations about these relationships. An important step of model evaluation and comparison is to understand and visualize the nature of modeled relationships. In this chapter we compare model responses along an age vector to contrast how the predictions of habitat elements will change with stand age. We also use a small set of relatively detailed data collected in a chronosequence study of stand dynamics to visually assess how well the models fit this well structured, but independent set of data for boreal spruce mixedwoods (ecosite 20). In addition, we used published results by Ferguson and Archibald (2002) and Perera et al. (2008), and a review by Brassard and Chen (2006) to further support the assessment of model generalizations.

Although a multitude of sophisticated statistical methods may be used in development of the models, their value for management lies in their ability to accurately predict stand conditions based on a restricted set of input variables. This capability, however, depends in large degree on their success in predicting stand conditions in areas that are external (geographically separate) from the local where data was collected for model development. Within any site, conditions will change over time, so if a model continues to predict well in sites where conditions are different from those found in the model development data set, then there is increased confidence that the model is sufficiently robust for use in scenario analysis. In this chapter we used data from an independent study of songbird habitat to conduct external validation of the models. In this data set snag density and down woody debris were collected in the field using a quick assessment technique over many different sites, and height was derived from FRI stand attributes.

We identified 4 objectives for model comparison:

1. Qualitatively compare predicted trends (shape of the curves) over time for habitat attributes among models. Regardless of whether the model is based on a specified mechanistic process or on fitting a curve to empirical data, this aspect of model behaviour characterizes how the model reflects changes in functional processes over time.

2. Qualitatively compare magnitude of predicted trends (elevation of curves) over time for habitat attributes among models. These differences between models will reflect specific differences in projected stand characteristics, for any point in time.

3. Qualitatively compare fit of the model to an independent dataset (ecosite 20 data), and to similar types of data summarized in relevant research publications. Given the high diversity of methods used in published papers, it is often difficult to make direct comparisons with published values.

4. Quantitatively compare predicted values versus observed values from the bird habitat study data. This will reflect how well the model can predict stand characteristics in areas outside of the model development local. This type of test is called external validation, and is a useful way to judge whether a model can legitimately be used to project future conditions.

Thus this section is not about evaluating development of the models, but rather focuses on assessing their outputs. The comparisons are used to characterize the strengths and weaknesses of each model and to recognize the uncertainties in modelling habitat elements. With additional field data further adjustments could be made to improve the models and increase their applicability to specific forest regions.

METHODS

Evaluation of the functional form and relative levels

Predicted values from the FORECAST and EMPIRICAL models described in Chapters 1 and 2 respectively were contrasted against each other, and compared against three sources of field data from the boreal region of northwestern Ontario. Most comparisons focused on the Black Spruce - Jackpine mixedwood forest unit, as we had

predictions from both models and an independent data set with tree height, snag density, and DWD volume for stands in this forest unit.

Extensive data on snag density and was published by Ferguson and Archibald in 2002. This data was collected in a study area that was dominated by mixedwood composition. The southern portion of the study area had extensive logging while the northern portion had minimal disturbance. A systematic sampling design was used to cover the range of forest types in each management unit in the study area. In order to compare the results of this study with the FORECAST and EMPIRICAL models the data were interpreted from the graphs and tables in the published report.

A more structured set of field data was collected by the stand ecology program at the Centre for Northern Forest Ecosystem Research as part of a wildfire chronosequence study. The purpose of this study was to document the natural benchmark states of ecosystem structure and function of ecosite 20 (Spruce-Pine / Feathermoss: Fresh, Sandy-Coarse Loamy Soil) sites over the stand development stages. Field measurements were conducted at a variety of sites at 5 to 10 year increments between the years 1994 and 2007.

A more targeted set of data was collected by Perera et al. (2008) to study structural conditions immediately post-fire using high-resolution aerial photographs taken from a helicopter. Photos formed a grid-based sample set, and field surveys were conducted to validate photo-interpretation techniques.

Where similar data was available from one of the three field sources comparisons were made with the FORECAST and/or EMPIRICAL models. In some cases comparisons could not be made between all data sources where appropriate data was not available. It was important in this analysis to ensure that datasets were representing similar field elements and where they were not it was important to understand the differences.

External evaluation of model performance

A test of predicted response versus observed response was conducted using an independent set of data collected over 3 years for a songbird habitat study (Rempel 2007), and predicted habitat element values for each observed stand based on the two models. Predictions were calculated using look-up tables in LSL (Kushneriuk and Rempel 2007) and Patchworks (Spatial Planning Systems 2008) which were applied to the current FRI (see Chapter 3).

At each of 947 sample locations the number of snags >20 cm dbh, and the number of logs >8 cm dbh were counted within a 10 m by 10 m plot. Down woody debris (DWD) was estimated as density of logs laying at an angle > 45°. Callipers were not used for determining exact size of the snags; threshold size was simply estimated after some field training. Stand conditions ranged from new clearcuts and new burns, to immature, mature, and late seral stage stands. Stand age was based on FRI, and ages were placed into 5 age-classes: 0-20; 20-40; 40-80; 80-100; 100+. To relate DWD to modeled units of DWD in m^3/ha, we simply did a coarse translation of the number of logs to volume, by assuming each log was a 1 m long cylinder with a radius of 10 cm. The purpose was simply to assess if there was any relative relationship between predicted volume and observed volume estimates. We also directly compared observed log density to predicted log density for the FORECAST model. The EMPIRICAL model did not provide separate estimates of log density.

RESULTS

Evaluation of the functional form and relative levels

Overall Large Snag Density

For large snags (>20cm dbh), in all forest types, the unmanaged FORECAST model was the only model that predicted a very high snag density during stand initiation (Figures 4.1a, 4.2a, 4.3a and 4.4a). The higher initial snag density in the unmanaged FORECAST model can be attributed to a higher number of residual dead trees following fire compared to the number of residual trees following harvesting in the managed model. The data from Ferguson and Archibald (2002) also indicated a higher density of snags in the initial time period (<60 years) for the two conifer classes (Figures 4.1B and 4.2B) but this initial snag density

was smaller relative to subsequent time periods than in the unmanaged FORECAST data. Note that the Ferguson and Archibald (2002) data was not summarized in such a way that the density of snags in very young stands (<60 years) could be explored to identify if there was a higher density in the first few decades followed by a drop in density. Also, the EMPIRICAL model may not have been based on data collected in stands young enough to observe the initial snag density.

In contrast, Perera et al. (2008) found high probabilities of finding stands with snag densities of between 500 and 900 snags/ha immediately post-fire, which is consistent with the FORECAST initial values for unmanaged forest stands. The Perera study was clearly and specifically focused on the immediate post-fire period, and in contrast with other studies, focused on estimating attribute probabilitiy distributions using boot-strap techniques rather than attribute means (Perera et al. 2008).

Black Spruce Mixed Conifer Snag Density

In order to compare the different models the vegetation classes that were the most similar were selected from each model. To explore the black spruce dominated mixed conifer (Sb Mix) class from the FORECAST model we selected the upland conifer class from the EMPIRICAL model, the black spruce upland class from Ferguson and Archibald (2002) and the ecosite 20 data. Overall, the ecosite 20 data indicated the highest number of snags (Figure 4.1a), followed by the EMPIRICAL model, the FORECAST model and then the data from Ferguson & Archibald (2002).

Not only did the form of the models differ between models and among comparison data sets, but the magnitude of predicted snag density also varied dramatically among models. Both of the FORECAST models indicate a rise in snag density beginning around 100 years (Figure 4.1b). This is consistent with the data from the ecosite 20 study and with the Ferguson and Archibald (2002) data. The data from ecosite 20 had the highest density of snags (> 650 snags/ha), particularly around 100 years (Figure 4.1A). This value is two orders of magnitude higher than the values observed by Ferguson and Archibald (2002) for this time period. The forest stands in ecosite 20 consist mainly of black spruce and jack pine with an understory of black spruce. Around 100 years the jack pine trees typically begin to die back, creating an increase in snag density, and the understory black spruce are released to grow into the canopy. As with the empirical data and the data from Ferguson and Archibald (2002) the ecosite 20 dataset contained no young sites to examine the snag density during

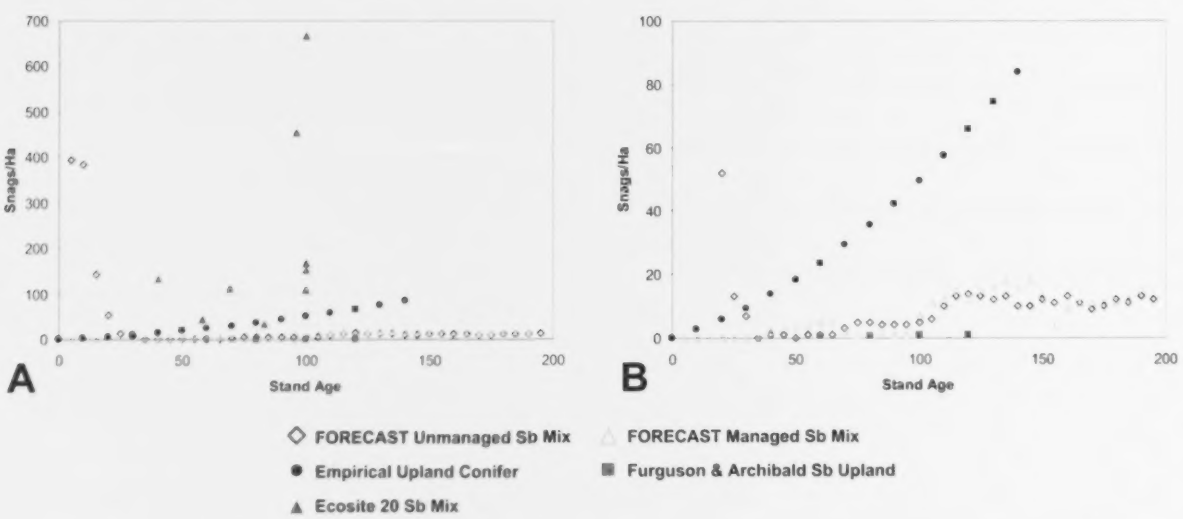

Figure 4.1. (A and B). Large snag (>20cm dbh) density for black spruce dominated mixed conifer stands (Sb Mix). The y-scale is reduced in Figure 4.1B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented. The ecosite 20 data is only represented in Figure 4.1A. Ferguson and Archibald (2002) values are 0.81 snags/ha at 0-60 years, 0.76 snags/ha at 61-80 years, 0.92 snags/ha at 81-100 years, and 1.0 snags/ha at >100 years.

stand initiation.

Conifer Mixedwood Snags

Both the managed and unmanaged FORECAST models indicate an increase in snags which occurs at a younger age (50-70 years) for the conifer mixedwood stands (Figure 4.2 a & b) than for the black spruce stands (100 years). This earlier increase in snag density may be attributed to a greater jack pine component in the stand composition. Since jack pine trees generally die younger than black spruce they will contribute to the snag density earlier. The Ferguson and Archibald data indicate a large increase in snag density in the >100 year class whereas the EMPIRICAL model begins to flatten out around 120 years at 40 snags/ha, approximately 13 times higher than the estimate from the Ferguson and Archibald (2002) data.

Trembling Aspen Snags

Similar to the other forest classes, the trembling aspen data from the unmanaged FORECAST model show a high density of snags in the early years of stand development, however the snag density is even higher in trembling aspen than in the other forest types (Figure 4.3 a).
The increase in the number of snags predicted by both FORECAST models was less gradual in trembling aspen than in either of the conifer models (Figures 4.3 a & b). The Ferguson and Archibald data had a large increase in snag density in the >100 year class.

Hardwood Mixedwood Snags

In the hardwood mixedwood stands of the managed FORECAST model there is a steep increase in snag density at year 100 followed by a decrease at year 120 (Figures 4.4 a & b) .This increase in snag density is not as pronounced in the unmanaged FORECAST model. The snag density of the managed FORECAST model for this forest type is more similar to the EMPIRICAL model than in any of the other forest types examined. The Ferguson and Archibald data values for hardwood mixedwood had the largest increase at 80-100 years, earlier than in most other forest types.

Down Woody Debris

Down woody debris (DWD) was examined using the black spruce mixedwood (Sb Mix) data to allow

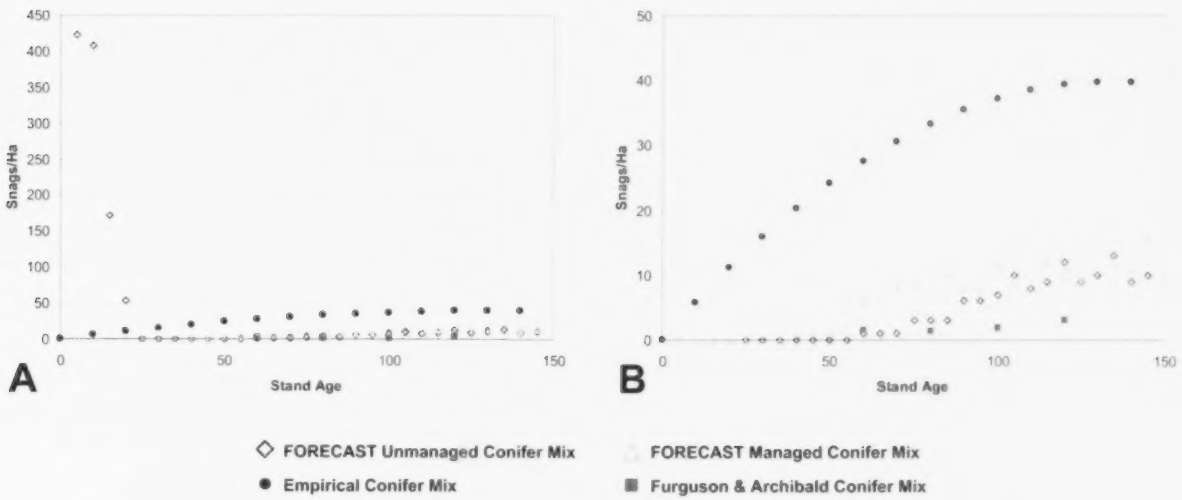

Figure 4.2. **(A and B).** Large snag (>20cm dbh) density for conifer dominated mixedwood stands. The y-scale is reduced in Figure 4.2B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented. Ferguson and Archibald values are 1.51 snags/ha at 0-60 years, 1.33 snags/ha at 61-80 years, 1.78 snags/ha at 81-100 years, and 3.02 snags/ha at >100 years.

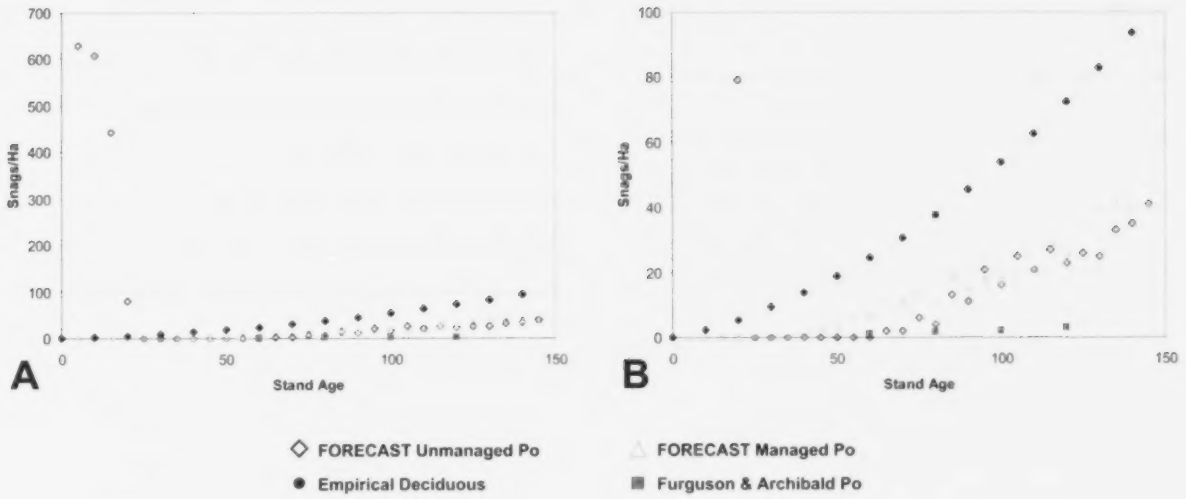

Figure 4.3. **(A and B)**. Large snag (>20cm dbh) density for aspen (Po) dominated deciduous stands. The y-scale is reduced in Figure 4.3B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented. Ferguson and Archibald values are 1.08 at 0-60 years, 1.81 at 61-80 years, 1.9 at 81-100 years, and 2.9 at >100 years.

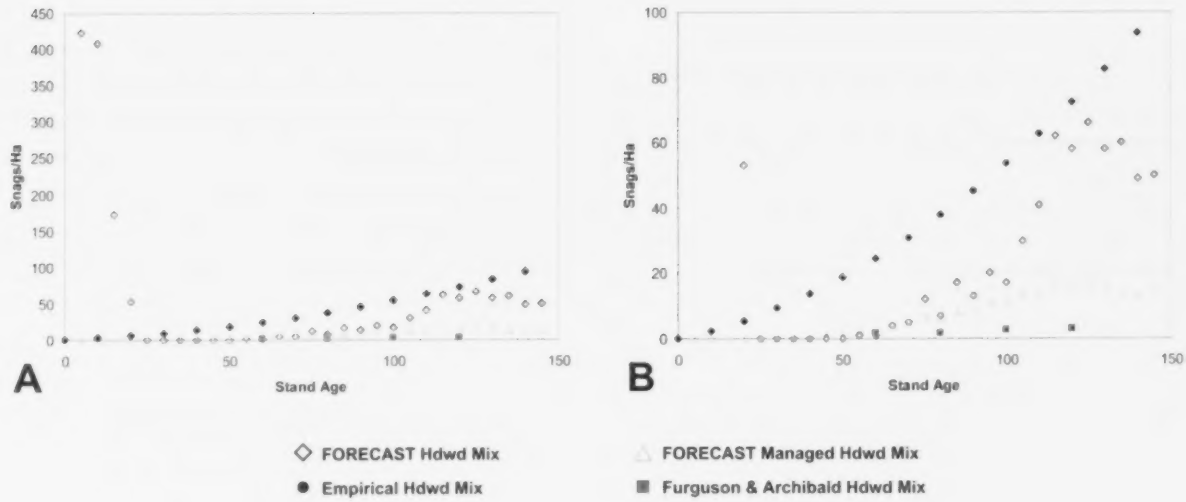

Figure 4.4. **(A and B)**. Large snag (>20cm dbh) density for deciduous leading mixedwood (Hdwd Mix) stands. The y-scale is reduced in Figure 4.4B to view data at lower snag densities therefore high initial snag densities in the FORECAST unmanaged model is not represented. Ferguson and Archibald values are 1.65 at 0-60 years, 1.82 at 61-80 years, 2.67 at 81-100 years, and 3.01 at >100 years.

comparison with the ecosite 20 data (Figure 4.5). The ecosite 20 data show a high volume of DWD in the early years of stand development; this is likely due to residual biomass from the previous stand. The high initial volume of DWD in the ecosite 20 data is followed by a decline to about year 80 and then a gradual increase. Both FORECAST models predict a drop in DWD in the early years followed by a steady rise to stand maturity (approximately 100 years) and then a decline. The managed FORECAST model has a larger drop in DWD volume during stand initiation and a sharp rise at 150 years. The EMPIRICAL model predicts a slow increase in DWD with a lower volume overall than the other models or the ecosite 20 data, and in general has predicted values an order of magnitude lower than the FORECAST model.

Perera et al. (2008) found high probabilities of finding stands with between 20 and 50 m^3/ha of DWD, immediately post-fire, which again is consistent with the initial conditions of the FORECAST model for unmanaged forest stands.

Black Spruce and Upland Conifer Height

The FORECAST managed and unmanaged tree heights were both higher than the empirical data and the ecosite 20 data (Figure 4.6). The unmanaged FORECAST data was very similar to Plonski's site class 1a curve, while the managed data was slightly higher. The empirical height curve flattened out around 80 years, which was not seen in the FORECAST model.

External evaluation of model performance

Age versus seral stage

There is potential that habitat model predictions will not correlate well with FRI age because of inaccuracies in estimates of actual stand age. As a partial test of this, we assigned each sample plot a seral stage (pre-sapling, sapling, immature, mature, and late seral stage) based on physiognomic characteristics of the stand. We then compared seral stage estimates with FRI stand age estimates (Figure 4.7), and it is clear that pre-sapling and sapling do not discriminate well (possible because of small differences in FRI age and the date of field sampling), and that mature and later seral stages do not discriminate well. The later problem may be due to poor FRI estimates for the date of stand initiation. Hence for ecological modeling, FRI data should probably only be grouped into estimates of 3 seral stages.

Tree Height

Modeled tree heights were compared against FRI tree heights, but there are potential errors in FRI tree heights if the data version does not include recent harvest activity. To sort out these errors, FRI stand age was plotted against tree height, and those records with a tree height of > 5 m for stands less than 10 years were obvious errors,

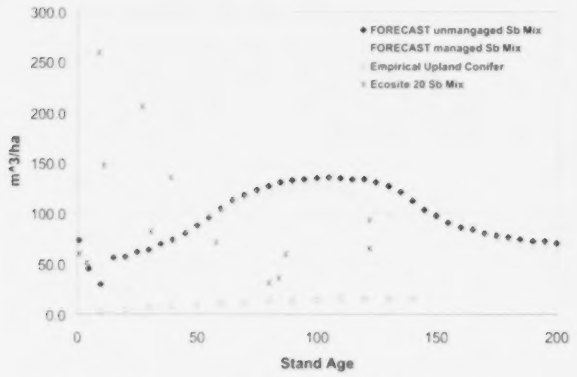

Figure 4.5. Down woody debris for black spruce dominated mixed conifer stands.

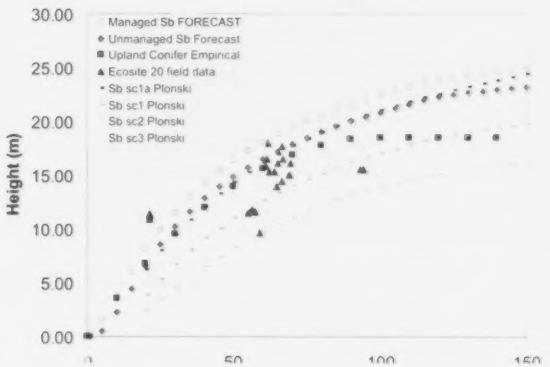

Figure 4.6. FORECAST, empirical and ecosite 20 height data overlaid on Plonski's Yield Tables for black spruce dominated mixed conifer stands.

and removed from the data. Likewise, records that indicated stands between 50-150 years, but with heights < 9 m were also removed from the data. A few legitimate records may have been removed, but overall we felt trimming unrealistic outliers was necessary (Figure 4.8 a), and the resulting curvilinear distribution (Figure 4.8b) was variable, but realistic.

Both the FORECAST model and EMPIRICAL model displayed a linear relationship between predicted and observed tree height. A perfectly modeled relationship would have a slope of 1.0, and an intercept of 0. The FORECAST model tended to under-predict FRI tree height, and had greater variance with the higher heights (Figure 4.8 c), whereas the EMPIRICAL model had a slope (1.082) approaching 1.0, and consistently did a good job of estimating FRI tree height. The strong fit of the EMPIRICAL model occurred in

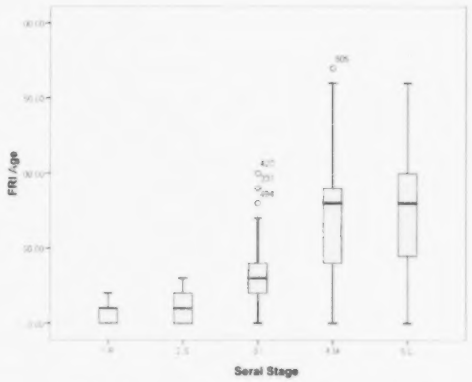

Figure 4.7. Comparison of seral stages (pre-sapling, sapling, immature, mature and late) assigned by field crews versus FRI stand age. Observers could only clearly discriminate 3 seral stages, as pre-sapling and sapling, and mature and late seral stages were confused.

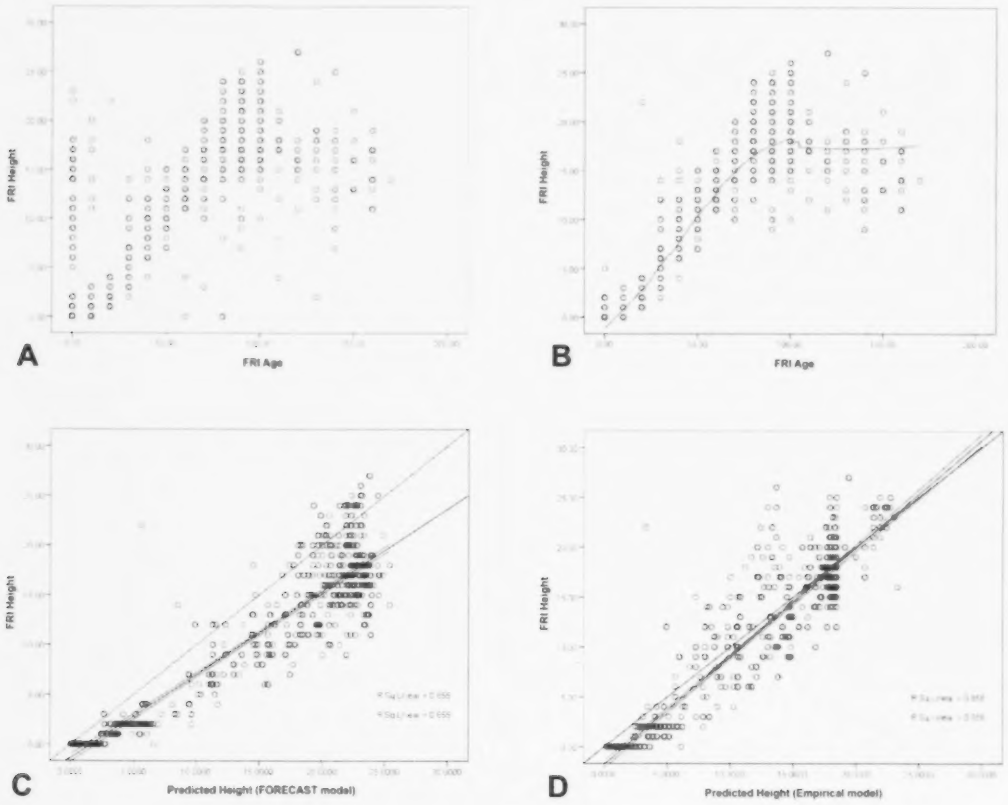

Figure 4.8. Tree heights versus age. (a) plot of FRI age versus height; (b) result of removing outlier data points; (c) & (d) regression of predicted overstory height versus FRI estimates of overstory height (outlier data points removed in (d)); both reference lines (slope = 1) and estimated slopes are given in (c) and (d).

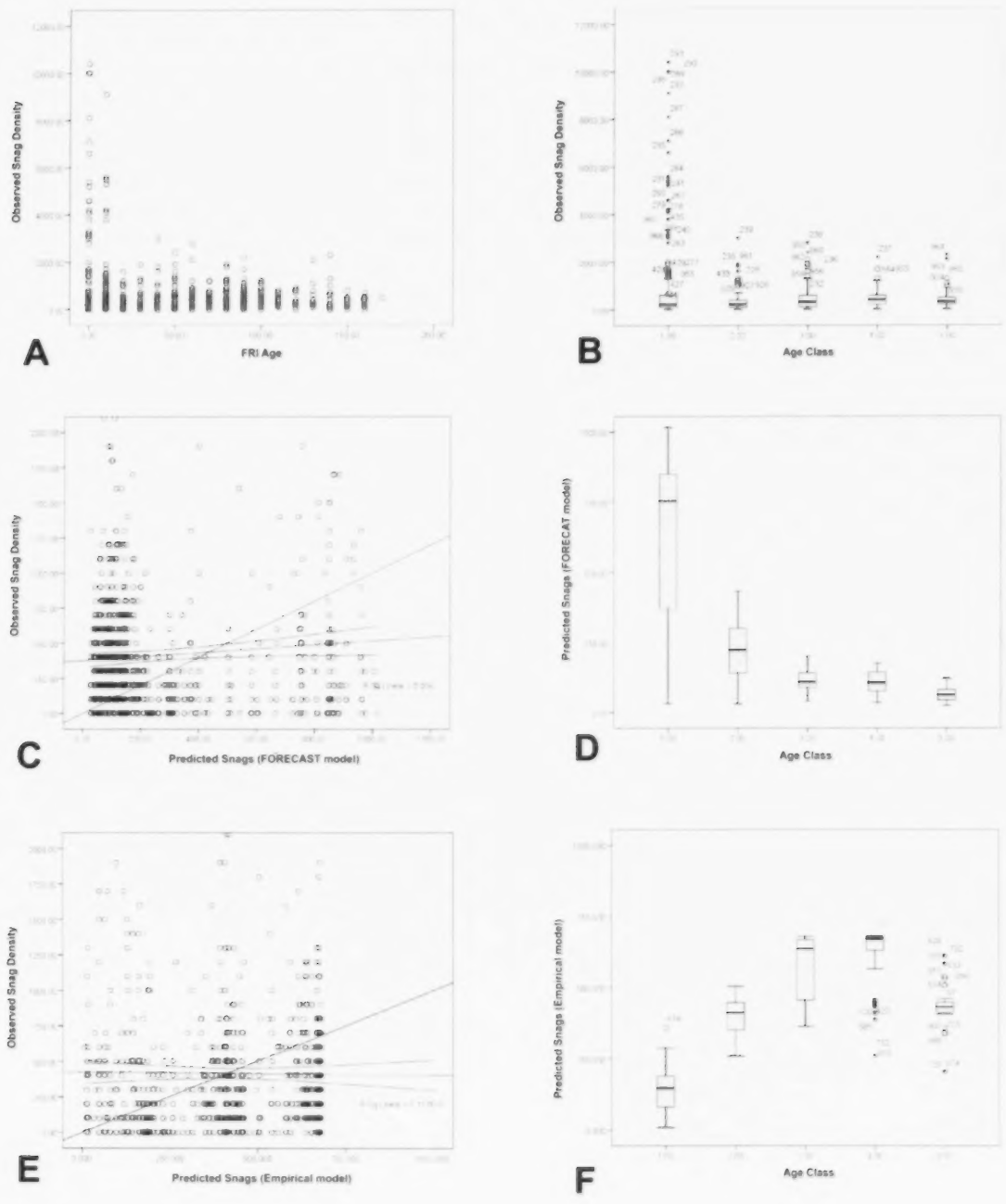

Figure 4.9. Snag density model evaluation. (a) stand age versus observed snag density; (b) dispersion of observed snag density among age-classes; (c) regression of predicted versus observed values for FORECAST model, and (e) EMPIRICAL model; (d) dispersion of predicted snag density among age-classes for FORECAST model and (f) EMPIRICAL model; both reference lines (slope = 1) and estimated slopes are given in (c) and (e). Observed values truncated at 2000 in (c) and (e).

part because that model predicts stand height will level off after 100 years. Variance was relatively consistent for height-classes 5 and above.

Snag density

Initial evaluation of the test data showed large variability in the snag density data (Figure 4.9 a & b), especially in the young age-classes. Data records indicated the source of disturbance associated with the stand, e.g., recent burn, recent burn and harvest, or harvest only, so we removed records associated with burns in our comparison of snag density under the "managed forest" scenarios. In regression plots of predicted snag density versus observed snag density, there was either a very weak or virtually no relationship between predicted and observed values, for either model (Figure 4.9 c & e). Box plots illustrating the dispersion of data among age-classes also revealed that models made very different functional predictions, with the managed FORECAST model showing sharp declines in the early years (Figure 4.9 d), and the EMPIRICAL model showing sharp increases (Figure 4.9 f). At the mature forest stage, the FORECAST model tended to under-predict the observed snag densities in the 100-150 snags/ha range, and the EMPIRICAL model tended to over-predict densities in the 500-700 snags/ha range.

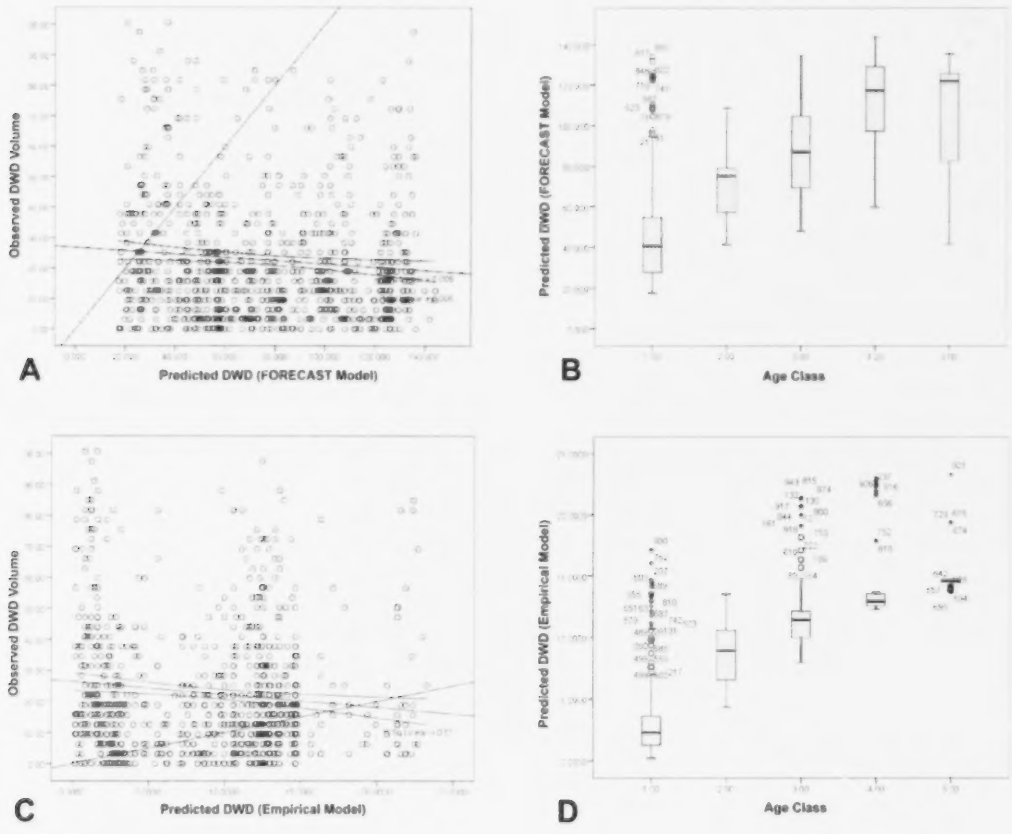

Figure 4.10. DWD model evaluation; regression of predicted versus observed DWD volume for (a) FORECAST and (c) EMPIRICAL model; dispersion of predicted values for (b) FORECAST and (d) EMPIRICAL models; both reference lines (slope = 1) and estimated slopes are given in (a) and (c). Observed values truncated at 100 for the plots for (a) & (c).

DWD Volume

Neither model for DWD volume revealed any relationship between predicted values and observed values (Figure 4.10 a & c), although both models had a similar functional response in terms of increasing levels of DWD over time (Figure 4.10 b & d). Some of this lack of fit may be due to the coarse translation of log density to estimates of DWD volume. To evaluate this possibility, we compared FORECAST estimates of log density to untransformed observed log density (Figure 4.11),

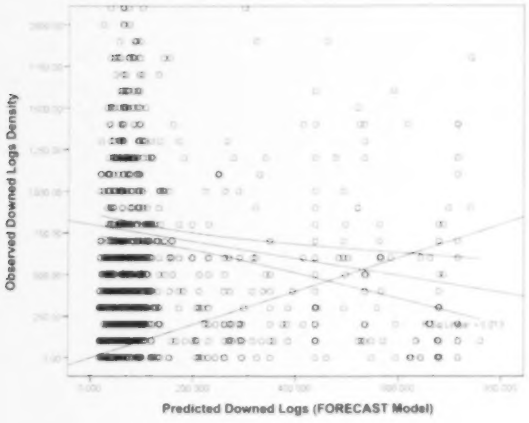

Figure 4.11. Regression of predicted downed log density (FORECAST model) versus observed downed log density. Observed values truncated at 2000. Both reference lines (slope = 1) and estimated slopes are given

and again, there was no predictive relationship between predictions and observations.

In terms of seral stages based on a field classification protocol, observed values of snags and DWD were highly variable among stages, but with slightly lower values in the immature seral stage (Figure 4.12).

DISCUSSION

It is apparent from this analysis that there remain a number of uncertainties in the modelling habitat elements such as snag density and DWD. Further field data collection and model adjustments may improve the accuracy and applicability of the models in this region. However, stochastic environmental factors may overwhelm any "signal" generated from a modeled relationship.

Snag density is especially variable. The only consistency is predicted and observed lower density for stands 30 – 50 years. The three main uncertainties in modelling snag density appear to be the density of snags at stand initiation (those remaining from the previous stand), the rate of increase in snag density and finally, the density of snags in mature and old growth stands. These uncertainties are generally consistent across forest types. For example, Perera et al. 2008 found abundance of residuals immediately post-fire varied widely among site categories, both within and among fires.

The density of snags at stand initiation is very

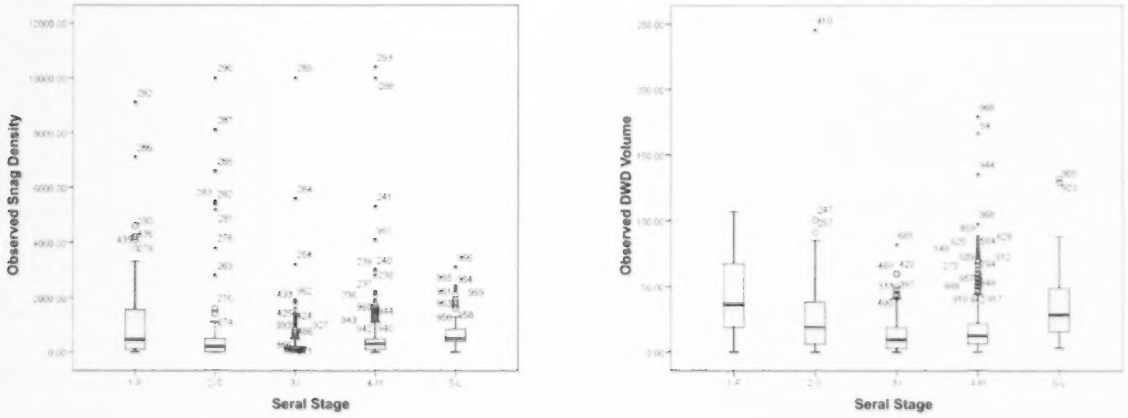

Figure 4.12. Observed dispersion of snags and DWD by field-estimated seral stage.

difficult to model since it is dependent on a large number of factors. Fire intensity will have a large impact on the number of trees that remain on the site to create snags in the new stand (Perera et al. 2008). In addition, various autogeneic processes during stand development will influence the number of residual stems (Brassard and Chen 2006). Natural disturbances such as fire or wind will vary depending on weather and terrain conditions as well as the level of human interference (e.g. fire suppression, post-disturbance harvesting). Stand conditions following forest harvesting will depend on current forest management policies and operator skill level. One thing that seems to be consistent across all data sources and models is that the high density of snags at stand initiation will not be present after a couple of decades, and this is supported by Perera et al. 2008. The decrease in snag density early in stand development corresponds with the increase in DWD indicated by the FORECAST models and the ecosite 20 data. Perera et al. (2008) found high probabilities of finding 500 – 900 snags/ha, immediately post-fire. These values are consistent with the high initial values predicted by the FORECAST models in unmanaged forests (Figures 4.3-4.5).

The rate of increase in snag density as stands mature tended to follow similar patterns between most data sources; however the actual densities were variable. The ability to predict and model the increase in snag density and the snag density of mature and old growth stands may depend on a combination of factors. In order to model snag density we need a further understanding of the stand dynamics including composition and self-thinning regime and we need to categorize the stand type and snag size appropriately to capture the variability in snag density over time within different forest types.

Ferguson & Archibald (2002) tested the relative contribution of various factors to the density of snags (stems/ha) and snag basal area (m^2/ha). They found that snag density was most strongly correlated to live tree basal area. Forests with high live tree basal area and older forests were associated with more snags. According to their research the relationships between live and dead tree basal area followed a ¾ power law with a slope of 0.74.

Snag size may influence the patterns of snag recruitment and retention. We have only examined large snags (>20cm dbh) but it may be beneficial in future studies to examine a variety of snag sizes. In the study by Ferguson & Archibald (2002) the distribution of snag size classes varied with forest age and forest type. In that study, the overall greatest number of snags occurred in young forests (0-60) and thereafter increased from 61-80 year old forests to the oldest forest age class(>100). This pattern was generally consistent for large and medium size snags however small snags were most numerous in the 61-80 year class (Ferguson and Archibald, 2002).

The low signal to noise ratio in snag and down woody debris data make them difficult to model or predict. Another complicating factor was the variability in the literature and among models for definitions of snags and DWD. Certainly, specifics concerning the size and decay classes of snags and DWD may influence the comparison between datasets. Perera et al. (2008) found the high variability of such definitions in the literature made comparisons and summary analyses virtually impossible.

Tree height has been well researched and documented. The main uncertainty identified in this analysis is whether tree height levels off around year 80 as shown by the EMPIRICAL model or if it continues to increase as indicated by Plonski's curves and the FORECAST model. External model validation indicates that the EMPIRICAL model, where height flattens off after 80 years, had an excellent fit with FRI estimated heights, with an almost 1 to 1 correspondence of predicted versus observed values.

The results of our model comparison suggest that neither empirical, process, nor hybrid process/ EMPIRICAL modeling approaches sufficiently capture the trends and variability in within stand-structure to serve the needs of realistic habitat modeling for snag density and DWD. Both empirical and process-based models bring us closer to understanding the dynamics of within-stand habitat (vertical) structure, but perhaps a missing element is the modeling of stochastic

events that affect initial stand conditions, and direct the development of stand structure. The high degree of resulting random or chaotic variability in stand structure may actually contribute to biodiversity values, and so perhaps management (and modelers) should not try to unduly constrain this variability.

There are two approaches to address this: either summarize the variability and express it as a central tendency (e.g., mean value), across all forest types and age-classes, or model the variability as a probability (density) function across all forest types. Our results suggest that for snag density, variability is highest at the early and late seral stages, and is consistently lower in the mid seral stages. Hence separate probability functions could be developed for a discrete number of age-classes (Figure 4.13). To the degree that variability plays a role in providing conditions necessary for the maintenance of biodiversity, the probability modeling approach may be a better approach than using a single mean value. Empirical data collection can provide the base or underlying probability function, but the process based models could perhaps influence or weight the probability function.

Of all the stand variables we examined, tree growth was the least variable. Nonetheless, variability in tree height does occur, and probability modeling would also be appropriate for this habitat element (Figure 4.14). With a relatively well defined variable such as tree height, process-based models could integrate with the models by predicting how the modal condition of tree heights will change, in a relative manner, given certain changes in climatic conditions or soil productivity. Given that snag density has been shown to be related to density of large trees within the stand (Ferguson and Archibald, 2002), this relationship could also feed into snag density estimates.

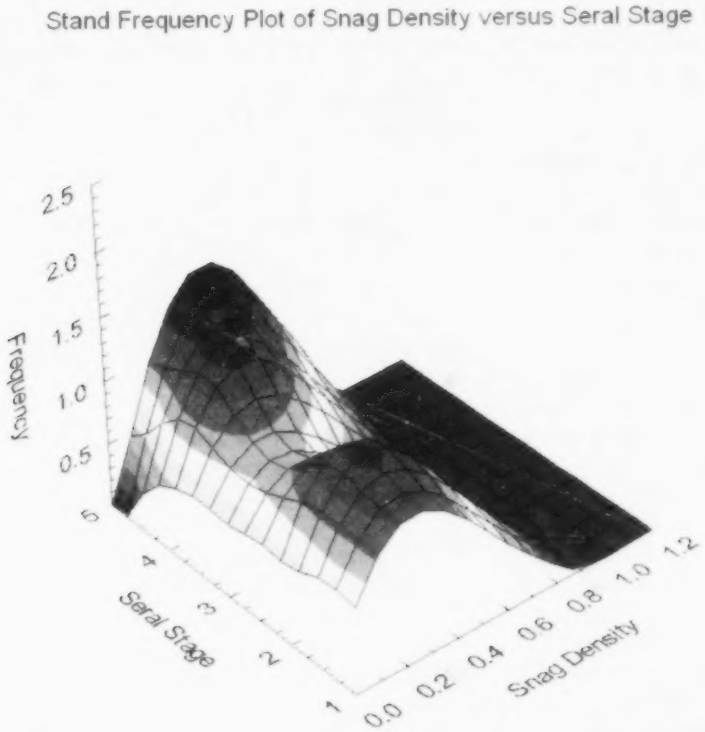

Figure 4.13. Conceptual view of a stochastic model of large-snag density, where modal values and the degree and form of variance changes with seral stage. The shape of the frequency distribution for Seral Stage 1 is based on Perera et al. 2008, and data presented in Figure 4.12

Modeling Approaches

Given the high degree of variability in habitat elements such as snag density and volume of down woody debris, it is questionable whether modeling these attributes will provide an increase in predictability of future forest conditions, or result in emergent new insights into the effects or effectiveness of alternative management strategies. Various approaches to modeling such attributes are discussed below.

Mean or modal value estimation

In this approach a single value is used to estimate the attribute across all stands. Both the magnitude and variance in DWD is held constant across all conditions. Ter-Mikaelian and Colombo (2008) found that because of the high statistical variability in DWD among stands, regardless of stand age, site class or stocking attributes, at present, this is the only statistically valid approach for predicting DWD. This approach would provide no discrimination among stands for these attributes, and therefore would be of very limited value for habitat modeling.

Frequency Distribution

The "mean value" approach can be extended in two ways. First, mean values can be calculated among strata (where justified), and second, the variance (or dispersion) can be calculated among strata. Our results indicate that variance is not static among age-classes, so estimates of frequency distributions (e.g., a frequency histogram) among age-classes is justified in terms of "predictable" changes in dispersion among age-classes.

Statistical Curve Fitting

Statistical curve fitting takes frequency distributions one step further by estimating a curve, or model, that fits the distribution. Curve fitting can be parametric or non-parametric, and can treat the data as a uniform distribution (e.g. regression) or as a segmented distribution (e.g., generalized additive models). Other than tree height, our results suggest a poor fit between estimated curves and observed values. Observed values had a very high degree of variability, especially in the early stand-age classes. This is the approach used in the EMPIRICAL models.

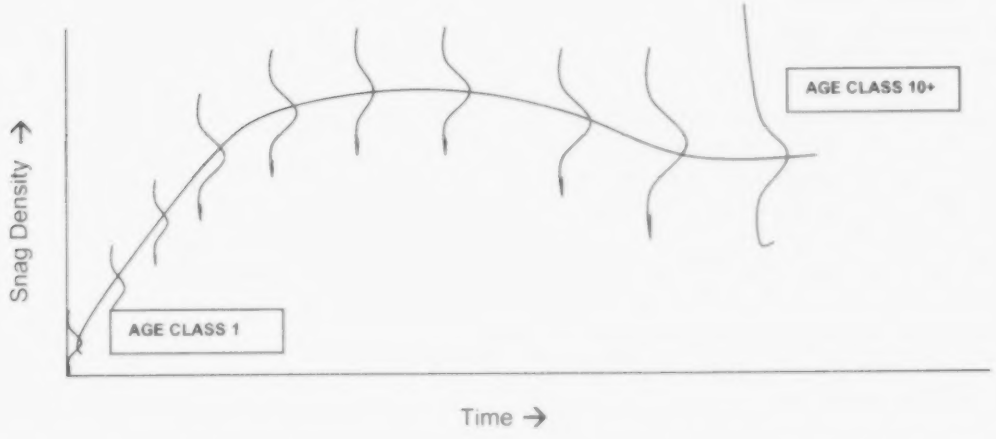

Figure 4.14. With a relatively well defined variable such as tree height, process-based models could integrate with the models by predicting how the modal condition of tree heights will change, in a relative manner, given certain changes in climatic conditions or soil productivity. Given that snag density has been shown to be related to density of large trees within the stand (Ferguson and Archibald, 2002), this relationship could also feed into snag density estimates.

Spatial Autocorrelation Modeling

Attributes within the physical and biotic environment are not randomly distributed, but rather spatially structured (clumped) because of structuring forces such as glaciation, geo-fluvial forces, and forest fires. This results in contagious statistical distributions across space. For example, snag density in neighbouring stands will tend to be more similar than stands far away if the neighbouring stands have a similar disturbance history and have similar site conditions. Habitat elements can be spatially modeled by recording spatial location of attribute values, and then using geostatistical methods such as simple kriging, universal kriging, co-kriging, or stratified kriging to interpolate values, or by applying simple non-parametric methods such as inverse density weighting.

Process (Mechanistic) Modeling

Process models attempt to simulate the mechanism of habitat element development based on environmental conditions such as light penetration, temperature, and soil moisture. In a highly controlled environment, this approach can work well, but in the natural environment initial site conditions, plus many other "autogenic" factors occurring during stand development swamp the predictions with unexplained variance. The result again is a poor fit with observed values, with the noted exception of tree growth.

Hybrid (Process/Empirical) Modeling

This approach uses mechanistic modeling, but "parameterizes" variables, and constrains output based on well structured empirical data, such as growth and yield plots. This is the approach used in the FORECAST model.

Matrix Age-Projection Modeling

The probability of transition between one class and another can be modeled using matrix modeling approaches. This is often used in modeling survivorship and fecundity (recruitment), but the approach could also be extended to modeling recruitment and "survivorship" of a population of living trees, snags and seedlings within a group of like-classified stands.

Stochastic Modeling

This approach simulates overwhelming unpredictability by modeling either a theoretical or empirical frequency distribution. Theoretical

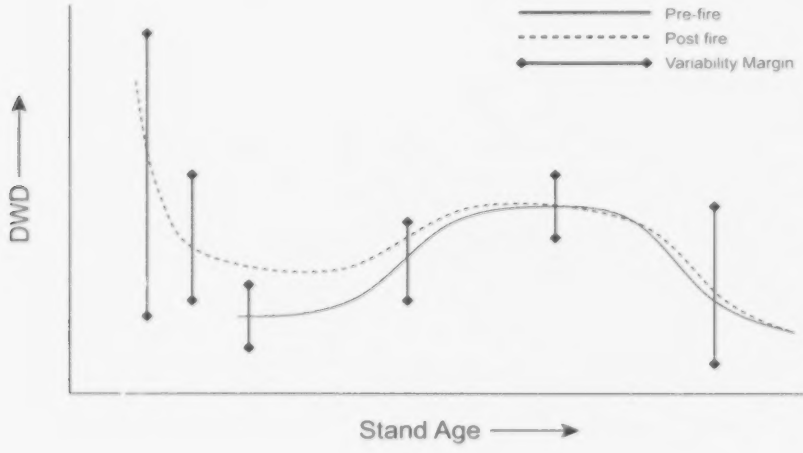

Figure 4.15. Mixed model of pre-fire and post-fire inputs to DWD, where pre-fire inputs are modeled stochastically, and post-fire inputs are modeled using a hybrid processes-based model.

frequency distributions (probability density functions) such as the normal (Poisson) require prior estimation of mean and standard deviation, while binomial (Bernoulli) distributions require an estimated probability of survivorship (or death). An empirical frequency distribution function can also be modeled through computer simulations using cumulative density functions (cdf), where a uniform random deviate is used to select a value from the cdf at each iteration of the model. The approach is appealing because it invokes few assumptions beyond the estimated frequency distribution, and better simulates the high degree of variability found in observed data. Perera et al. (2008) provide frequency distributions for snag density and DWD based on boot-strapping of observed data, and then go on to create cumulative density functions which are directly amenable for stochastic modeling.

Mixed Model Approach

If, during the life-cycle of habitat element development, the emphases of forces on succession change between stochastic and mechanistic, then it would be appropriate to incorporate different approaches to modeling (e.g., stochastic and process based models), but change the weighting of these models over time. For example, the predicted values of snag density could be determined primarily by stochastic models for the early seral stages, but then primarily by process models in mid seral stages (Figure 4.15). Late seral stages would again be dominated by stochastic model outputs. To do a better job of estimating future forest conditions in spatial maps, these approaches should also be combined with spatial methods such as stratified kriging. A matrix stage-projection model could conduct the basic "accounting", and pull the various modeling outputs together.

Modeling Conclusions and Suggestions for Habitat Elements

Based on our analysis of alternative modeling approaches, including FORECAST, Elkie's EMPIRICAL models, Plonski's growth & yield curves, with comparisons to data collected from Ontario's growth & yield program and Morris's Full-tree harvesting program, habitat data for external validation from the Rinker Lake songbird study (Rempel 2007), and with critical assessment of papers by Ferguson and Archibald (2002), Brassard and Chen (2006), Perera et al. (2008), and Ter-Mikaelian and Colombo (2008), we come to following conclusions, and make the following suggestions:

Average Top Tree Height

This attribute has relatively high predictability, and could be modeled either by empirical or hybrid models. Separating models into a set of age-class structured stochastic models (Figure 14) would add realism, and the precision and accuracy of models will improve with appropriate and better stratification (e.g., site class). Using a random deviate for spatial projections would also add realism by incorporating variability into future forest projections, but specific stand-level predictions would be spatially arbitrary. Assessment of management scenarios would certainly be valid at an aggregate level such as the management unit, but some preliminary evaluation revealed that even averaging over a 50 ha moving window would provide useful discrimination among scenarios.

Snag density

This attribute has low predictability, and at the moment, probably treated best as a set of random normal deviate models, where variable is based on either Gaussian or empirical frequency distributions. Frequency distributions are possibly skewed at younger age classes, but because of zero-value truncation, even using a normal random deviate will result in proper skewing as the mean value approaches 0. Again, note that using a random deviate would add generality by increasing the percentage of stands with values below a threshold level of snag density, but results would be spatially arbitrary.

DWD volume

This attribute has low predictability, and at the moment, probably treated best as a set of random normal deviate models, where mean value is constant across age-classes, but where variance is lowest at mid-age classes.

Percent canopy closure

We did not have independent data to model for this element; however, this attribute follows a rather well defined successional path, and could be reasonably modeled as a random normal deviate, stratified only by 4 seral stage classes (Young, Immature, Mature, and Late). Variability changes among age classes, with highest variability in Immature and Late seral stages, and highest level of canopy closure in the Mature seral stage.

Shrub density

We did not have independent data to model for this element; however, this variable is related to seral stage and ecosite, as open canopy conditions (in rich soils) at stand initiation provide excellent conditions for shrub growth, while closed canopies in the mature seral stage (in poor soils) provide very poor conditions for shrub development. Conditions improve in late seral stage as the canopy begins to open and light can penetrate. At the moment, probably best to model the attribute as a set of random normal deviate models stratified by ecosite (or vegetation community class) and 2-3 seral stages (young & immature, mature, and late seral stages). A similar approach was used by Rempel et al. (1997) for modeling moose browse.

In conclusion, models and modeling approaches should be selected based on a clear understanding of application objectives. Models of internal stand structure should be used cautiously, and modelers should error on the side of selecting the simplest, but most defensible models, even if this means loosing resolution in terms of projecting alternative management actions. For the purpose of evaluating management scenarios and future forest conditions, it may be best to use well behaving surrogate variables (e.g., tree height) in developing habitat models than using other preferred habitat variables that cannot be predicted well.

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